# ASTRONOMY

February 1983
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## Vesta: A World of Its Own

## How to Sketch Deep Sky Objects

## Photoelectric Photometry from Your Backyard

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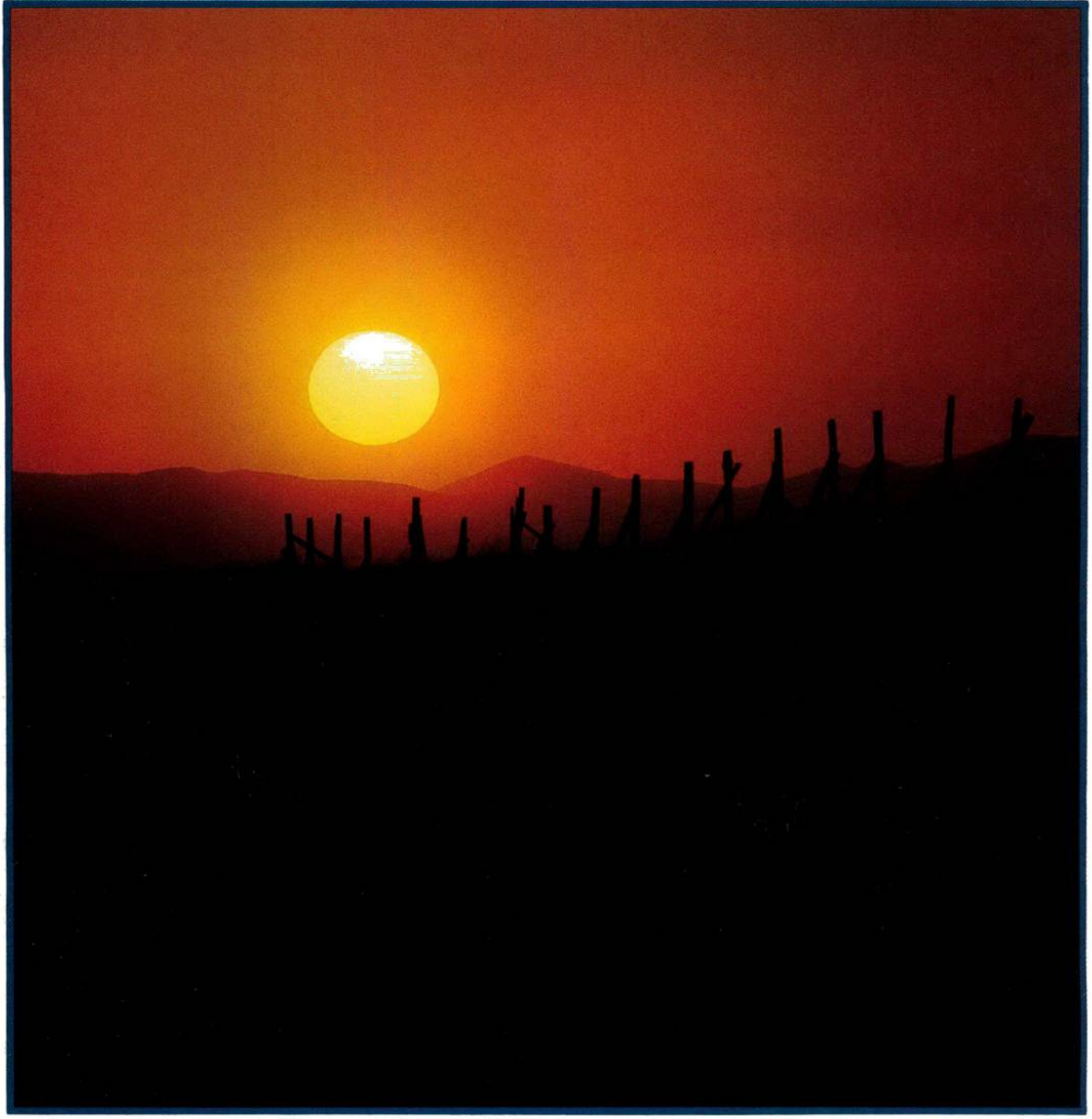

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***Telescopes Shown:*** *(top) Meade 8″ Model 2080 with optional photographic systems, including 4″ Schmidt-Cassegrain Photo-Guide Telescope; and (bottom) Meade 10″ Model 2120 with optional 2″ f/12 Photo-Guide Telescope.*

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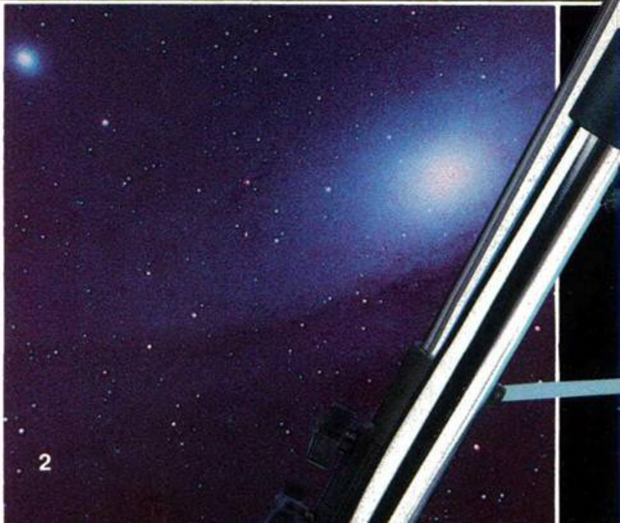
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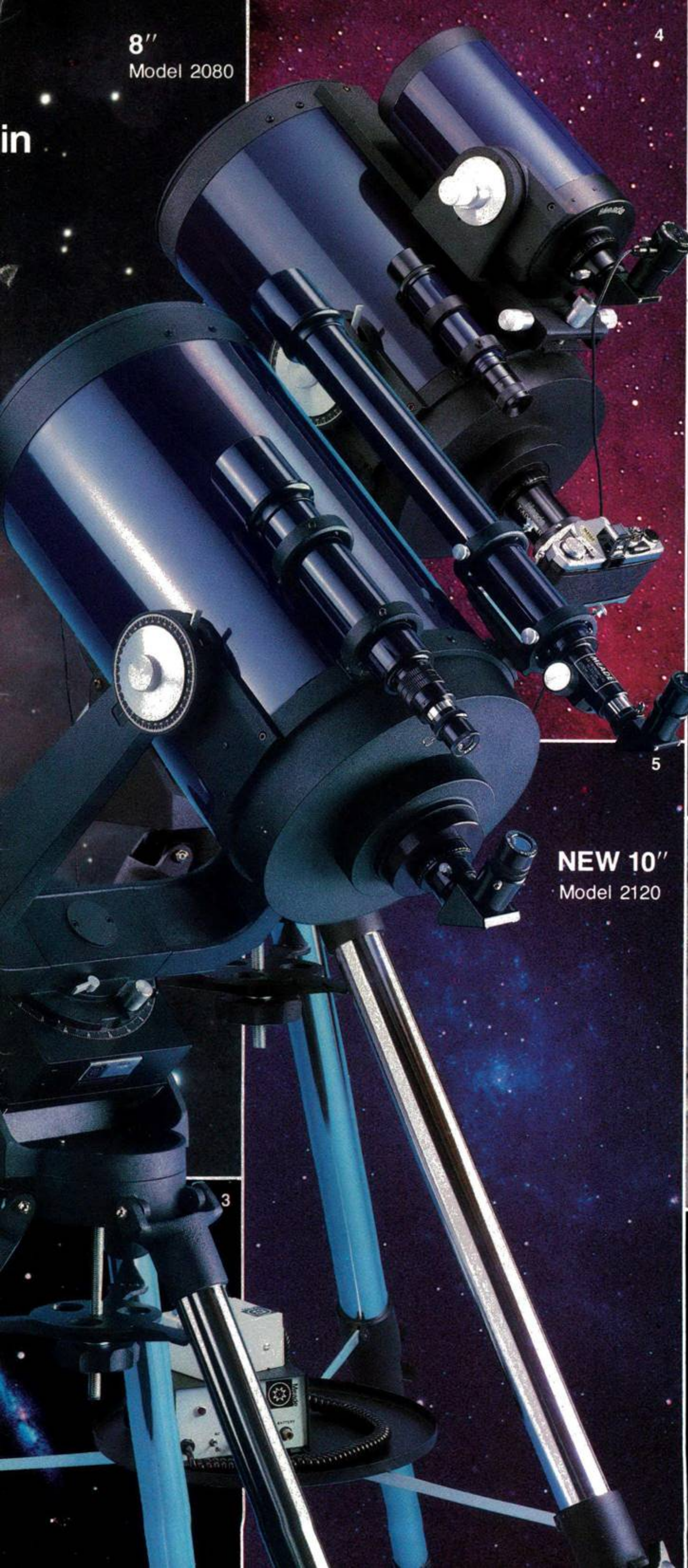

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**All astrophotographs shown on these pages were taken through off-the-shelf, unmodified Meade 8″ Model 2080 Schmidt-Cassegrain telescopes.** For further technical details on these and many other astronomical photographs, send for your free copy of the Meade Schmidt-Cassegrain Astrophoto Brochure. (Alternately, the complete Meade 52-page General Catalog is available at $3.00 by First Class Mail and includes the Astrophoto Brochure at no additional charge.)

**Key to Photographs**
**1, 2, 3, 5**—Leo Henzl; **4, 7**—Emery Hildebrand; **6**—Paul Roques; **8**—John Sanford

**1.** Orion Nebula M42; exposure time 50 mins. **2.** Andromeda Galaxy M31; 60 mins. **3.** Galaxy M82; 60 mins. **4.** Milky Way in Sagittarius (50mm piggyback photo). **5.** Spiral Galaxy M33; 75 mins. **6.** Spiral Galaxy M51; 90 mins. **7.** Omega Nebula M17; 40 mins. **8.** Moon—Clavius region.

# ASTRONOMY

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**Cover:** If the universe were very little different than it is, there would be no life, either here on Earth or anywhere in it. Yet we *are* here — conscious of ourselves, our planet, our Sun, our Galaxy, this universe. Is it simply luck that we are here, one life-filled universe among countless billions of lifeless universes, or might our universe require life somewhere in it? We examine the "anthropic principle" in the story beginning on page 14. Sunset photograph by Roy Gephart. These pages: the Moon and Mercury on the morning of October 15, photographed by Jack Troeger.

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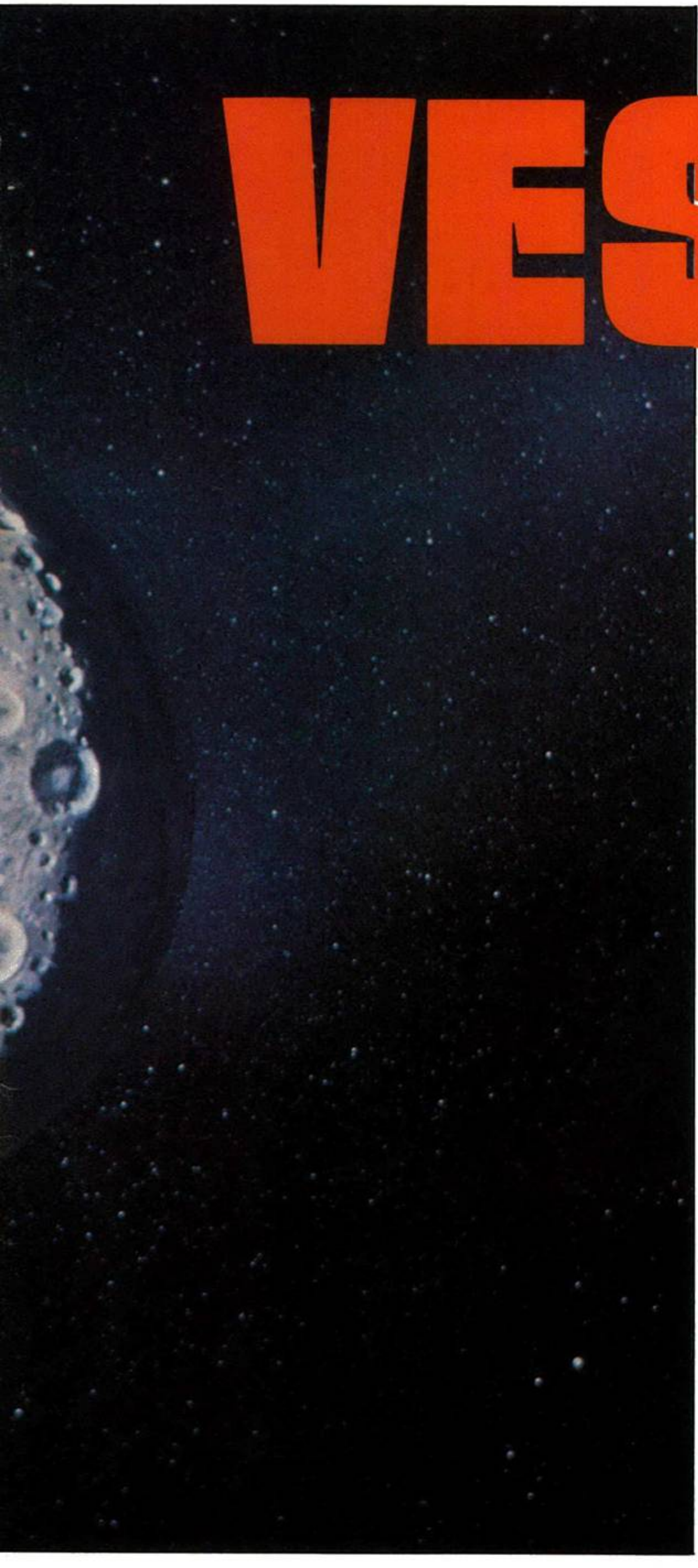
# VESTA

## a World of Its Own

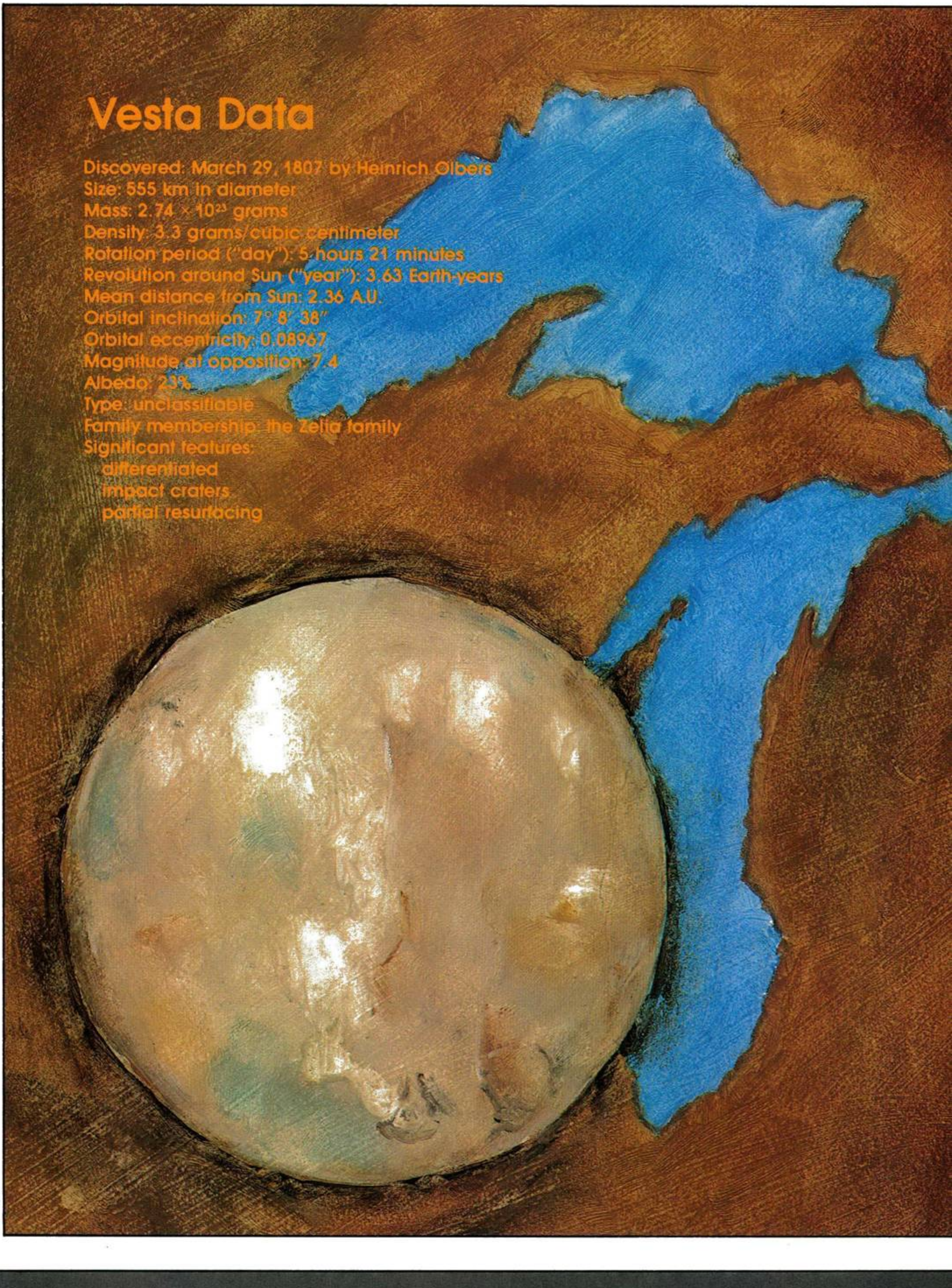
by
William K. Hartmann



Battered by impacts, flooded with lava, and internally differentiated, Vesta (seen here in author Hartmann's conception) may be one of the strangest asteroids known.

# Vesta Data

Discovered: March 29, 1807 by Heinrich Olbers
Size: 555 km in diameter
Mass: $2.74 \times 10^{23}$ grams
Density: 3.3 grams/cubic centimeter
Rotation period ("day"): 5 hours 21 minutes
Revolution around Sun ("year"): 3.63 Earth-years
Mean distance from Sun: 2.36 A.U.
Orbital inclination: 7° 8′ 38″
Orbital eccentricity: 0.08967
Magnitude at opposition: 7.4
Albedo: 23%
Type: unclassifiable
Family membership: the Zelia family
Significant features:
  differentiated
  impact craters
  partial resurfacing



T.L. Hunt

It wasn't very long ago that asteroids were seen by astronomers as a rag-tag collection of tiny points of light. They were faint, virtually indistinguishable from each other, and turned up in such numbers on photographs as to deserve their nickname "vermin of the skies." No longer do they engender such genial contempt.

In recent years, as observing techniques have improved in sophistication, astronomers have learned more about the specific properties of individual asteroids. During this time, our conception of asteroids has changed from an assortment of anonymous "blips" to an array of individual worlds. And paralleling this evolution in our thought, one asteroid in particular — Vesta — has emerged to become one of the more intriguing asteroids known. Vesta, it seems, may offer unique clues that tie together such seemingly diverse problems as meteorite origin and planetary evolution.

Vesta was discovered in 1807 by the German astronomer Heinrich Olbers. Despite its long observational history, few significant facts on it appeared. Its size had been estimated — at a couple hundred kilometers — but that was about all. This has changed in the last few decades. One of the most important of these new data has been the light curve — that is, the asteroid's periodic fluctuation in brightness due to rotation. With most asteroids, this change in brightness happens as a result of an elongated shape: because the broad sides of the asteroid reflect more light than the ends do, when the sides face toward the Earth, the asteroid appears brighter. In the case of Vesta, the maximum light curve amplitude is rather small — only 14%. This suggests that Vesta is relatively spheroidal compared to many other asteroids, which appear to be out-of-round by 20%, 50%, or even more.

Vesta's roundness is not too surprising. With a diameter of 555 kilometers, it is probably the third largest asteroid, trailing after Ceres (1025 kilometers) and Pallas (583 kilometers). Throughout the solar system, bodies this large are relatively round because their gravity overcomes the rigidity of their internal material, and deforms them into an equilibrium shape — a ball. Only the smaller bodies are rigid enough to hold an irregular shape, the result of countless previous collisions with other asteroids.

By 1970, interest in Vesta began to grow: planetary scientists Thomas McCord, John Adams, and Torrence Johnson applied new observing techniques to measure the spectra of asteroids at infrared wavelengths. These wavelengths are important because they offered clues on mineral composition. Most asteroids in the main belt between Mars and Jupiter seemed to cluster into several broad types, such as a generally stony S type, a more metal-rich M type, and a carbonaceous C type. Vesta, however, didn't fit into any one of these categories: since its spectrum was unique, it was designed type U, or unclassified. Measurements of its *albedo* or reflectivity, showed another oddity. Vesta reflects about 23% of the sunlight striking it; it thus has a much lighter surface than most asteroids, which have typical albedos of 4% to 18%.

In short, Vesta has an unusual type of surface rock — but what is it? The conventional practice among asteroid scientists is to compare the spectrum of reflected sunlight from an asteroid with the spectra of sunlight reflected from meteorites. Since meteorites are probably chunks of asteroids, meteorite types ought to match asteroid types. While some problems exist, so far this

## How Do Astronomers Study Asteroids?

The name itself is a tip-off: asteroid means "star-like," and that's exactly how they appear in the telescope. Even Ceres, the largest of the asteroids with a diameter of 1025 kilometers, has a disk less than a second of arc across and appears essentially stellar. As a result, during all the years since asteroids were discovered in 1801, astronomers paid scant attention to these little worlds apart from cataloging their orbits.

Up to about 10 to 15 years ago, this was still the rule. But by then astronomers had developed an array of instruments that produced a nearly explosive growth of data when brought to bear on asteroids. Today, asteroid scientists have a veritable panoply of techniques to further their research:

*UBV photometry*. By observing the reflected light from asteroids in three broad bands of the spectrum, astronomers can classify an asteroid into one of several general types that corresponds to its composition. In addition, measurements of asteroids' regular fluctuations in brightness reveal rotation periods, and this in turn gives some indication of shape.

*Visible-infrared spectrophotometry*. Careful measurements made in the near-infrared can disclose subtle differences among asteroids. These differences arise from the unique ways each type of mineral in the surface rocks imprints its "signature" in the spectrum of reflected sunlight. These signatures can be used to distinguish between various sub-types of asteroid.

*Radiometry*. Radiometry is heat-sensing. Combining a thermal brightness with brightness at visual wavelengths allows astronomers to derive an asteroid's diameter to within an accuracy of 10% — provided they make some reasonable assumptions about the asteroid's surface materials.

*Polarimetry*. Analyzing how light is polarized when it reflects from a surface material tells a lot about that material. By studying the polarization of light from an asteroid, planetary scientists can infer the surface texture and, combined with UBV photometry, derive the values of the asteroid's albedo and diameter — a valuable check on other methods.

What does the future hold? The two most important developments in instrumentation are the Infrared Astronomy Satellite (IRAS) and the Space Telescope. The recently launched IRAS will be able to detect all asteroids brighter than magnitude 17, which effectively means any asteroid having a medium albedo that is bigger than 5 to 10 km across. When IRAS has finished its surveys, astronomers expect that the total number of known asteroids will jump tenfold from the present 3,000 to about 30,000.

The Space Telescope will be launched in 1986. From Earth orbit, its 94" mirror will be able to image the disks of Ceres, Pallas, Vesta and a few of the other large asteroids directly. But unfortunately, its resolution will still be fairly coarse: for example, the disk of Ceres will be only 18 pixels across and Vesta 13. This is sufficient to detect any bright and dark patches and plot their locations, but not good enough for geologic mapping — to do that, we'll have to send probes into the asteroid belt for a closer look.

approach has been fruitful. For example, type C asteroids are clearly related to carbonaceous chondrite meteorites. The common type S asteroids are a bit more mysterious, but are probably related to the ordinary stony chondrite meteorites, which formed 4.5 billion years ago and never melted. And type M asteroids are probably stony material that is somewhat richer in metals.

But applying this simple approach to Vesta yielded a provocative result. In the early 1970s, McCord, Clark Chapman, Glenn Veeder, and others mapped absorption features in Vesta's spectrum that could be identified with the mineral pyroxene, commonly found in terrestrial lava. Further work showed that the best meteorite match was with a type of meteorite called a *basaltic achondrite*. In this unusual variety of meteorite, the glassy spherules called chondrules have been destroyed by melting and are absent — hence the name *a*chondrite. Thus, the rock is not in a primitive state, but has been melted and reformed into an igneous rock like a terrestrial basaltic lava — a rock type also common to the Moon and Mars. In fact, basalts seem to be the normal product when a planet whose interior is heated beyond the melting point erupts lava on its surface.

But how can this be? It suggests that Vesta underwent enough internal heating to have melted and been resurfaced by erupted lavas. Planetary scientists generally believe that the smaller a body is, the faster and more easily it will lose heat from its interior, and the less likely surface melting will be. According to spectral studies, even thousand-kilometer Ceres — almost twice as big as Vesta — has a very primitive unmelted surface. Basalts cover only about 15% of the surface of our Moon — which has a diameter of 3500 kilometers — while the rest is non-volcanic igneous rock. Thus it is puzzling to find evidence of lava resurfacing on Vesta, while other bodies of similar and larger sizes remain essentially unchanged.

Meanwhile, spectroscopists narrowed down the type of meteorite that best matched Vesta even further. Asteroid scientists have now generally agreed that Vesta best fits the spectrum of a special sub-type of basaltic achondrite meteorite called a *eucrite*. A typical eucrite is a piece of lava approximately 4.5 to 4.6 billion years old, composed of about 60% by weight of pyroxene and about 40% plagioclase feldspar. Some eucrites show internal structures that suggest they solidified inside an underground magma chamber or deep pool of lava, rather than in a moving flow of lava on a planetary surface.

University of Arizona geochemist Michael Drake and his co-workers have followed out the logical implications of the Vesta-meteorite match and suggest that the eucrite meteorites in our museums are actually pieces of Vesta. The idea is exciting because if the identity of the meteorites were certain, we could begin realistic modeling of the geologic processes of melting and mineral formation inside a 555-kilometer asteroid that never comes closer than 200 million kilometers.

But other researchers have questioned the conclusion, pointing out that it is difficult to knock pieces off Vesta and then get them to Earth rapidly enough. Cosmic-ray exposure ages of eucrites show they have traveled in space in the form of meteorite-sized chunks for only 1 to 10 million years. Orbital calculations suggest that it is unlikely for a chunk to have been broken off Vesta and arrived at Earth in so short a time. Drake postulates, however, that larger fragments may have broken off from Vesta, were gravitationallly perturbed into Earth-crossing orbits, and

**A close-up of Mars' moon Phobos — an object astronomers think could be a captured asteroid.**

## Asteroid Types

The name *asteroid* encompasses a remarkably broad variety of objects. They range from primitive bodies such as Ceres, which seems to be made of material practically unchanged since the early days of the solar system, to highly altered objects such as Vesta. But one recurring problem that plagues all aspects of asteroid studies is completeness. Present-day survey methods are strongly biased toward finding large, bright objects that move quickly. As planetary scientists begin to survey more impartially with new satellite observatories, we can expect to see this scheme filled out in more detail — and still other categories added to the roster.

*Type C.* These asteroids comprise about three-quarters of all asteroids; are commonest in outer part of belt; have silicate-and-carbon (carbonaceous chondrite) mineralogies; are dark, with albedos of about 3.5%, and have flat spectra; can be found in all size ranges; are considered primitive and relatively unprocessed samples of the solar nebula. Examples: Ceres, Hygeia, Fortuna.

*Type S.* Comprise about 17% of all asteroids; are located chiefly in inner belt; have silicate mineralogies mixed with nickel-iron (spectra indicate presence of pyroxene and olivine); are medium-bright, with albedos of about 15%; can be found in all sizes; may be processed (differentiated). Examples: Juno, Astraea, Hebe.

*Type M.* Comprise a few percent of all asteroids; have featureless, though somewhat reddened, spectra; have albedos around 15%; may be pure nickel-iron, in which case are probably the cores of differentiated bodies that have had their silicate outer layers removed by collision. Examples: Psyche, Lutetia, Kalliope.

*Type F.* Have orbits that cluster with the M types near middle of belt; have albedos that run close to 3%; their spectra are flat. Example: Interamnia.

*Type P.* Orbit outside the main belt, clustering most numerously around 4 A.U.; are dark, with albedos around 3.5%; their spectra are similar to type M. Example: Sylvia.

*Type D.* Have albedos around 3%; are very red in color; are found chiefly at the outer edge of the main belt, in the two Trojan groups (60° ahead and behind Jupiter), and among the outer satellites of Jupiter. Example: Thule.

*Type R.* Rare objects in inner half of belt; albedos are not quite as bright as E, ranging upward from around 15%; have red spectra with strongly pronounced absorption features. Example: Dembowska.

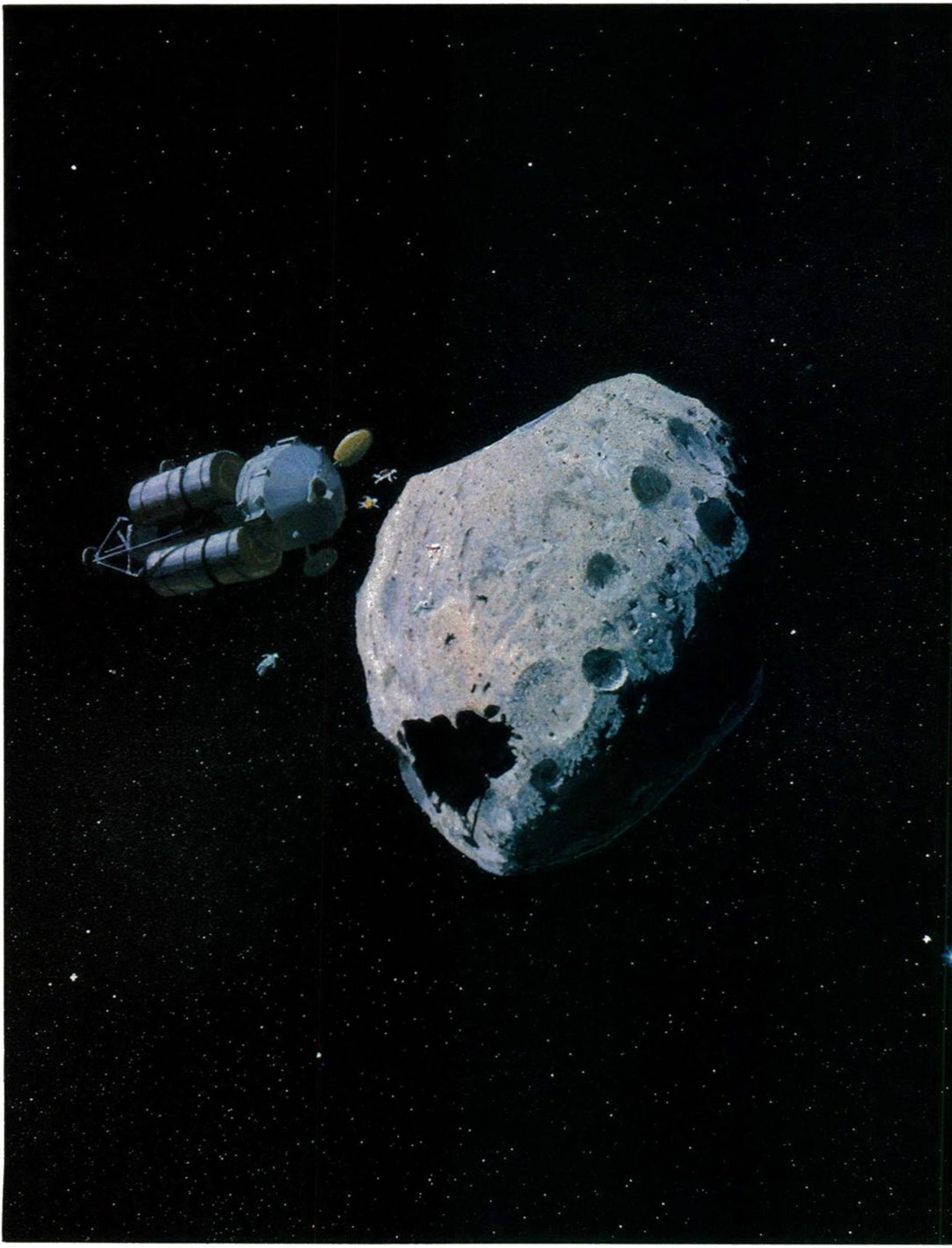
*Type E.* Small and bright (albedos greater than 23%); have flat spectra; tend to orbit near the inner edge of the belt, around 2 A.U. Example: Nysa.

*Type U.* As befits a "catch-all," type U (for unclassified) contains all those that don't fit into one of the above. Examples: Vesta, Pallas.

Type is one way to classify asteroids; family membership is another. Where type gives an indication of an asteroid's physical characteristics, family membership hints at its origins. In the 1920s, the Japanese astronomer Hirayama Kiyatsugu noted that the orbits of certain asteroids had many similarities with others. Hirayama took this to mean that the asteroids in each of these so-called families had been part of a larger body that disrupted. Now called *Hirayama families* after their discoverer, these groups offer planetary scientists a way to reconstruct what pre-collision "proto-asteroids" may have been like.

For example, astronomer Benjamin Zellner and his co-workers have reconstructed the parent body that may have given rise to the Nysa family. In their model, the large M-type asteroid Hertha lies at the core, with E-type Nysa and several assorted smaller bodies forming part of the surrounding mantle. The missing parts are probably fragments too small to be identified. Another family has M-type Budrosa and a similar asteroid, Ginevra, making up most of the core, while R-type Dembowska and U-type Carmen represent what's left of the mantle. In all, more than a hundred families have been identified.

NASA photo



painting by W.K. Hartmann

then shattered into smaller pieces under subsequent impacts. Perhaps there is an as-yet-undiscovered eucrite asteroid already in an Earth-crossing orbit that is the source of our eucrite meteorites. This body might be a piece of Vesta, or perhaps a piece of some other basalt-clad asteroid.

Whatever the case, it's intriguing to speculate on what Vesta might actually look like. Of course, we have no maps because we have not yet obtained close-up photos of it — or any other asteroid, for that matter. However, the latest research by University of Hawaii observer Michael Gaffey is beginning to provide clues. Gaffey has been recording the spectra of asteroids at different moments as they turn. In this way he can look for assorted mineral types on all sides of the asteroid. Gaffey's work suggests that when the dimmer side of Vesta faces us, we're looking at a patch of dark, basaltic material — which might account for much of the fluctuation in Vesta's light curve. The most logical assumption is that this material is basaltic lava — perhaps a large sheet that flooded some ancient impact scar, just as basaltic maria fill the largest impact basins on our Moon. A brightening in the light curve about 90° away from this feature hints at the existence of a bright crater. Vesta's overall color and albedo suggest that it is light tan, somewhat ruddier in tone than many other asteroids.

Does the painting on pages 6 and 7 thus show the real appearance of Vesta? We won't know until we send a reconnaissance probe on a mission through the asteroid belt to map and identify the geochemistry of Vesta and many other asteroids at first hand. Until then, we can be tantalized by the realization that each and *every* asteroid has its own story to tell — but that Vesta's may be one of the most interesting.

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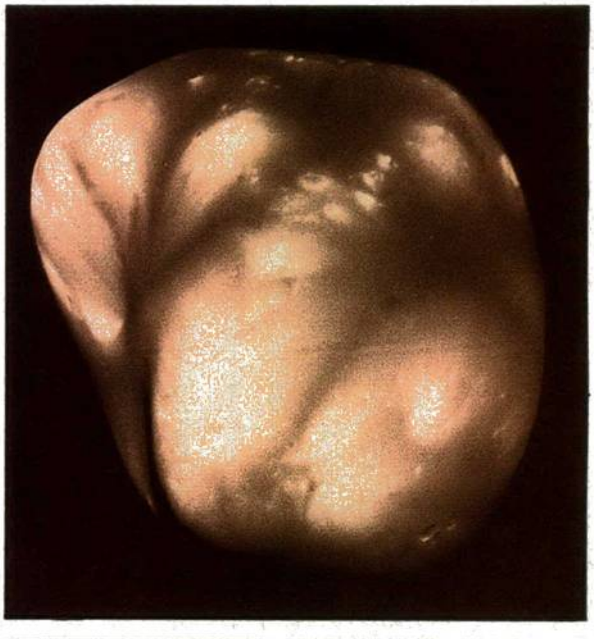
**Deimos — another captured asteroid?**



NASA photo

**Carrying its survey crew, a manned scout ship derived from the old Apollo Lunar Modules descends toward an asteroid.**

## Missions to the Asteroids

With the current starvation-level budgets being forced on planetary science, any asteroid mission is a pretty distant prospect. But scientists are still making plans and hope that NASA's long-term, low-budget plan for solar system exploration — which includes at least one mission to the asteroid belt — will be approved. It is likely that when such missions get the green light, they will follow what has become the traditional sequence: flybys first, then orbiters, landers, and finally, sample-returns.

The simplest mission, a flyby, would yield images about equal to those the Voyagers took of the jovian and saturnian satellites. Encounter velocities would be around 5 km/sec, with a maximum ground resolution of about 1 kilometer. This would allow scientists to map the entire surface of the asteroid with enough accuracy to do preliminary geological surveying. Other properties, such as surface chemistry or mass distribution, would receive little attention because the time available in a flyby is too short.

On the other hand, an orbiter could either "keep station" with the asteroid in its path around the Sun or actually orbit it. The latter would be more costly in terms of propellant (especially when several asteroids are to be encountered), but would provide better data. Camera resolution would be a few meters — sufficient for fairly detailed geology — and the images would resemble those that the Mariner and Viking probes took of the martian satellites Deimos and Phobos. In addition, the long time spent near the asteroid would permit chemical analysis of the surface materials by gamma-ray spectrometers and other remote-sensing techniques.

A lander augments these studies with a much more detailed analysis of one or more sites on the asteroid itself. Furthermore, while a soft-lander can be more sophisticated, an array of simply instrumented hard-landers spaced around the object might provide more data, as well as a "global" view of the asteroid. Eventually, a sample-return mission is a must, if only because a terrestrial laboratory can run far more exacting tests than a robot probe.

The two most tempting asteroids for a mission are Ceres, because it's primitive and the largest one known, and Vesta, because it has been differentiated — but these two are followed closely by dozens of other objects worthy of investigation. Calculations show that even a simple flyby probe could easily encounter three, four, five or more asteroids during a mission that might last a decade.

While only unmanned probes are on the boards at present, manned missions will certainly occur some day — and they might be spurred by economic reasons since even a small nickel-iron asteroid has mining possibilities. But such projects, though in the realm of the technologically possible, would cost a sum that is politically unsupportable for the foreseeable future.

# From Chaos to Consciousness

*by Mike Corwin*

Our species has a strong sense of community with the universe. From earliest recorded times, myths have connected the most mundane happenings to the grandest cosmic events. Astrology is an obsolete means of preserving this sense of connection between ourselves and the universe. On the other hand, science — the destroyer of literal myth — seems to deliberately disconnect us from the mystery and majesty of the universe. It sometimes appears as though all beauty and meaning must be carefully extracted from any scientific explanation.

At the deeper levels of modern science, this need not be the case. We now know that in a most profound and beautiful sense we are truly children of the universe, and we can develop a scientific worldview that satisfies some of our fundamental psychological needs without creating a schism between our rational and feeling selves. Current physical theories allow us to trace how the universe evolved from an unimaginably hot, dense mixture of radiation and particles to a comfortable haven for conscious life.

Our Sun is a fairly ordinary star, one of about 300 billion stars that make up the Milky Way Galaxy. Our stellar system is one of about 30 other galaxies that form a cluster known as the Local Group. And clusters of galaxies like our Local Group lie throughout the universe in all directions, as far as the most sensitive telescopes can see. By the early 1930s, an amazing fact about the nature of our universe had become apparent: every cluster of galaxies in the universe is moving away from every other cluster. The universe in expanding.

The most obvious interpretation of an expanding universe suggests that the clusters of galaxies were closer together in the past than they are now. As we go back further and further in time, the matter of the universe crowds in upon itself more and more until it consists of an infinitely dense, hot, expanding state of energy. This condition is known as the Big Bang. Current calculations indicate that it occurred some 15 to 20 billion years ago.

By one-thousandth of a second after the Big Bang, expansion had decreased the temperature and density of the universe to levels where the presently accepted physical laws apply. One minute after the beginning, the stuff that would eventually form stars, planets, and our own bodies appeared in the familiar guise of protons, neutrons, and electrons.

After about three or four minutes, the temperature had dropped sufficiently for the protons and neutrons to hold together — they could form the nuclei of atoms. Protons significantly outnumbered the neutrons, so only one helium nucleus (two protons and two neutrons bound together) formed for every eleven or so protons. Since a single proton is the nucleus of hydrogen, the simplest chemical element, the only elements in any significant amounts in the early universe were hydrogen and helium.

Expansion and cooling continued. Several hundred thousand years after the Big Bang, the universe was cold enough for negatively charged electrons and positively charged nuclei to combine and form hydrogen and helium atoms. The stage was set for the formation of galaxies and the first stars.

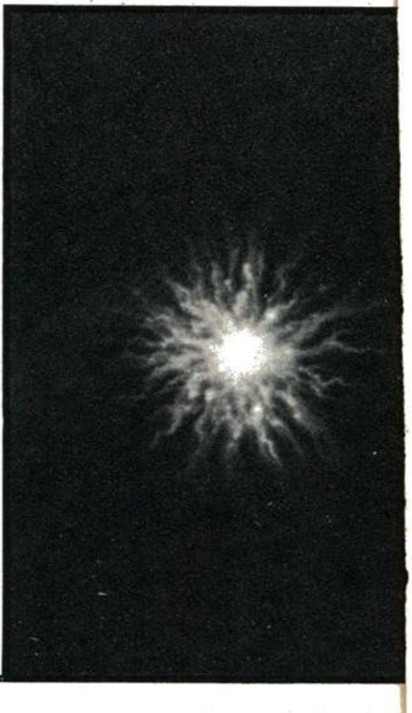
The early universe was almost perfectly homogeneous, its material spread evenly thoughout. Once the universe had expanded and cooled sufficiently for atoms to form, however, matter began to clump together under the influence of gravity. Gravitational collapse caused small density differences to grow into large ones. As these proto-galaxies grew denser, smaller clumps within them condensed to become the first generation of stars in the universe.

The proto-stars fell in on themselves, growing hotter and denser. Deep inside, atoms were knocked apart by their energetic motions in the rising heat to a state in which electrons once again became separated from nuclei. When internal temperatures reached about 10 million degrees, hydrogen nuclei were moving fast enough to overcome the repulsion between their like positive charges and begin the nuclear fusion reactions that converted hydrogen into helium and energy.

After the hydrogen had been depleted in the cores of these first stars, their interiors began to contract and

T.L. Hunt

*Astronomers believe that the universe began with a "Big Bang." After the explosion, the rapidly expanding universe was entirely composed of radiation. Expansion cooled the cosmos, and the elementary constituents of matter condensed from energy — protons, electrons, and other particles. Inhomogeneities in the universe, now largely composed of hydrogen nuclei, allowed matter to clump into galaxies and stars. Today, the only remnants of the violent birth of the universe are the observed recession of distant galaxies and the 2.7° K background radiation — the fading echo of a 20-billion-year-old explosion.*



heat up. At a temperature of about 100 million degrees, they began to convert the helium within them to carbon. This new stability continued until the helium was used up; the stars collapsed again and heated up again. Carbon fueled these hotter fires, and oxygen became the new "ash." In this manner, the more massive stars (about five times the mass of the Sun) produced nuclei of all the elements up to and including iron. They eventually contained an iron core surrounded by shells of progressively lighter chemical elements, all enveloped by an outer shell of leftover hydrogen and helium.

But a disastrous sequence of events occurs when a star initiates nuclear reactions involving iron — disastrous for the star, but very fortuitous from our point of view. Nuclear reactions involving iron absorb rather than liberate energy. Without internal energy to support them, the massive stars rapidly collapsed. Electrons within them interacted with protons to produce neutrons and neutrinos. Neutrinos are massless particles that move at the speed of light. They are notoriously unsociable members of the subatomic particle "zoo" and do not usually interact with the more familiar species. The core of a collapsing sun is extremely dense, however, and even the neutrinos could not easily escape.

Neutrinos were released in such quantities that their passage through the stellar interiors created a pressure that not only stopped the collapse but reversed it and literally blew the stars apart. Such explosions leave behind dense bodies consisting almost entirely of neutrons — known, logically enough, as neutron stars.

We call the explosion of a massive star a *supernova.* It is a crucial step in the evolution of life and intelligence. Only in supernova explosions are elements heavier than iron produced. Along with other heavy elements synthesized over the lifetime of the star, the trans-iron elements are explosively thrown out into a galaxy. The destruction of massive stars sows the seeds of life throughout the galactic fields.

When galaxies like our Milky Way formed, the initial supply of hydrogen and helium gas was not completely converted into stars. Some of this original material still remains scattered in vast low-density clouds between the stars. Over the history of the galaxy, this leftover material has slowly collapsed to form second- and third-generation stars.

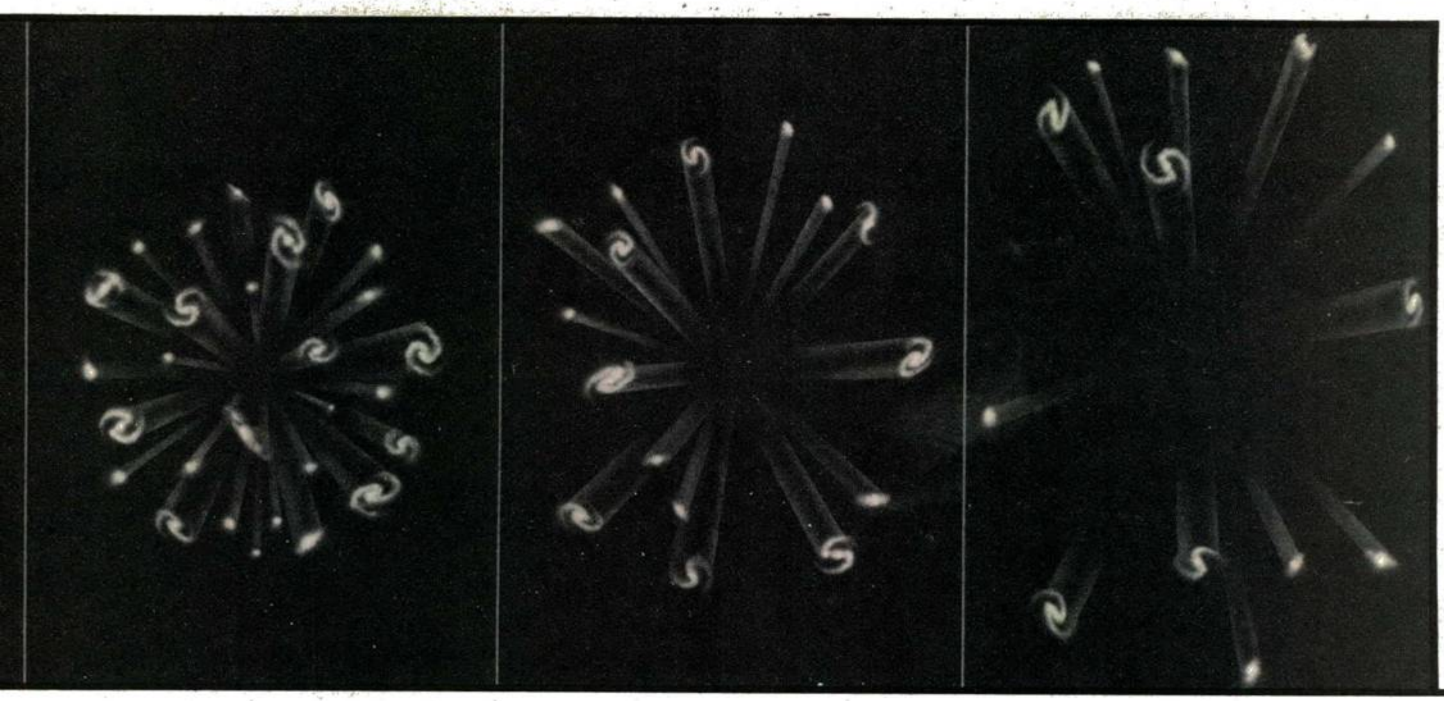
But there is a significant difference between these later-generation stars and their predecessors. The heavier elements produced and distributed by supernovae have infiltrated the primordial material and influence the evolution of stars in a way that is of the utmost significance to us. The presence of heavy elements and the dynamics of star formation can result in the creation of Earth-like planets. If our present understanding of star formation is correct, our Galaxy may contain millions of Earth-like worlds.

Whether or not planets are common, the formation of Earth-like worlds occurred at least once. Our Sun and its attendant planets were formed some five billion years ago. Because of its particular mass and composition, the Earth has gone through geological evolution of a nature specifically suited to the evolution of life.

Very early in its history, the interior of our planet melted, releasing gases into the primitive atmosphere. One effect of this early outgassing was the formation of oceans and rivers. Driven by energy from the Sun, chemical evolution began to form more complex structures from the simple raw material available at the Earth's surface. Organic molecules like amino and nucleic acids can be formed in this way. Interactions between these molecules can lead to the formation of still more complex molecules, as well as the formation of physical structures that bear strong resemblances to cell membranes.

Some three-and-a-half to four billion years ago, chemical structures capable of duplicating themselves evolved, and life began on the Sun's third planet. Early life diversified through complex interactions with the environment, producing after billions of years of evolution the animal species we know today. Although we do not know precisely when, intelligence developed on Earth, and the universe became conscious.

This 20-billion-year journey seems at first glance tortuous and convoluted, and our very existence appears



Victor Costanzo

to be the merest happenstance. On closer examination, however, we will see that quite the opposite is true — intelligent life seems predestined from the very beginning. Darwin's concluding remark in *The Origin of Species* that "there is a grandeur in this view of life" is even more appropriate today.

At one level, the universe is beyond doubt more complex and profound than our finite minds can ever comprehend, but at another level it is incredibly simple. The complexity of the events outlined above flows inevitably from the "rules" that governed the beginning of the universe — its initial physical conditions. We can describe these conditions in terms of several basic properties: the fundamental forces of nature and the large-scale properties of today's universe.

The four basic forces of nature are — in order of decreasing strength — the strong nuclear force, the electromagnetic force, the weak nuclear force, and the gravitational force. They are the four known ways in which matter and radiation interact to create the fundamental structure of the universe.

The *strong nuclear force* binds neutrons and protons together to form nuclei. It is involved in nuclear reactions, like the nuclear fusion taking place within stars. The *electromagnetic force* is an interaction between electrically charged particles, which results in oppositely-charged particles attracting one another. The electromagnetic force of attraction between negatively charged electrons and positively charged nuclei is responsible for the formation of atoms. The *weak nuclear force* is responsible for radioactive beta decay, for example, which allows a free neutron to decay into an electron and a proton. The weak force is also at work when neutrinos interact with other particles. Finally, there is *gravity* — by far the weakest force known in nature. It is an attractive force exerted between all matter and radiation in the universe, governing the formation of stars, galaxies, and clusters of galaxies.

The remaining four basic properties describe the large-scale structure of the universe: its present rate of expansion, its present density, the ratio of the number of photons (particles of electromagnetic radiation) to the number of nuclear particles (neutrons and protons), and the fact that the universe is homogeneous and isotropic (on the large scale, matter is evenly distributed in all directions). The homogeneous and isotropic nature of the universe and the ratio of photons to nuclear particles have been constant properties from the earliest describable moments of the universe. However, the rate of expansion is slowly decreasing because of gravity, and the density of the universe is decreasing because of its expansion.

Using the eight basic properties of the universe and the known physical laws, we can trace the sequence of events leading from the Big Bang to our existence. In this sense, our existence is "explained" and no more mysterious than the development of a flower from a tiny seed (though only the most insensitive could fail to see the deepest mystery in this).

To carry this analogy a little further, the type of flower that develops depends on the "initial conditions" of the seed. Given different genes, flowers of different sizes, colors, and fragrances develop. Given different initial conditions in the universe — that is, properties different in some way from the eight listed above — what would the universe be like? Would there be consciousness in this different universe — would it be self-aware? Since consciousness in any scientifically conceivable form is inevitably linked to life, we must have some idea of the minimum requirements for life in order to answer the last question.

The key to life and intelligence is complexity. Of all the forces present in nature, only chemical (electromagnetic) forces between atoms can produce any reasonable degree of complexity. We will therefore proceed on the assumption that life requires chemical interactions involving complex molecular structures.

At least four events seem to be crucial to the development of life:

*A Hydrogen-Dominated Universe.* Hydrogen is the fuel that allows a star to have a long and stable lifetime. Stable stars are necessary for a constant supply of energy over the time periods sufficient for life and intelligence

*From "The Ancient of Days" by William Blake.*

to develop. Without hydrogen, there would be no water. Though life might possibly exist without water, the substance has several unique chemical properties that make it ideally suited as a constituent of living organisms.

The preponderance of hydrogen results from a delicate balance among the various initial conditions. The original nucleosynthesis occurred when approximately 13 percent of the nuclear particles were neutrons. For example, if the strong force that binds nuclei together were slightly stronger, nucleosynthesis would have occurred much earlier — when about 50 percent of the nuclear particles were neutrons. Helium nuclei would then dominate the universe, but no hydrogen would be left over. A slight weakening of the weak force, which is responsible for the decay of neutrons, would have had the same result — neutrons would have decayed less quickly, so more of them would have been available.

*The Formation of Galaxies and Stars.* Some clumping of the matter in the universe is almost certainly a minimal requirement for the existence of life. If the ratio of photons to nuclear particles were higher than it actually is, the formation of stars and galaxies would not have been possible. A greater quantity of radiation or a smaller amount of matter would result in a universe with a density too low for the gravitational collapse of galaxies and stars by the time sufficiently low temperatures were reached.

The formation of stars and galaxies also requires a rather restricted range of homogeneity. If the early universe had been perfectly uniform, no clustering of matter could have occurred. If the universe had been more than just very slightly clumpy, however, all the matter in the universe would have wound up within black holes.

*The Production and Distribution of the Heavier Elements.* Heavy elements are essential to the complex chemical structures of life. The relative strengths of the four fundamental forces play a crucial role in the production and distribution of these elements. If the gravitational force were slightly weaker, all stars would be stars like our Sun in which supernova explosions could not occur. The elements produced in their furnaces would be fated to remain within them when they ended their lives. A universe such as this would be a dead end.

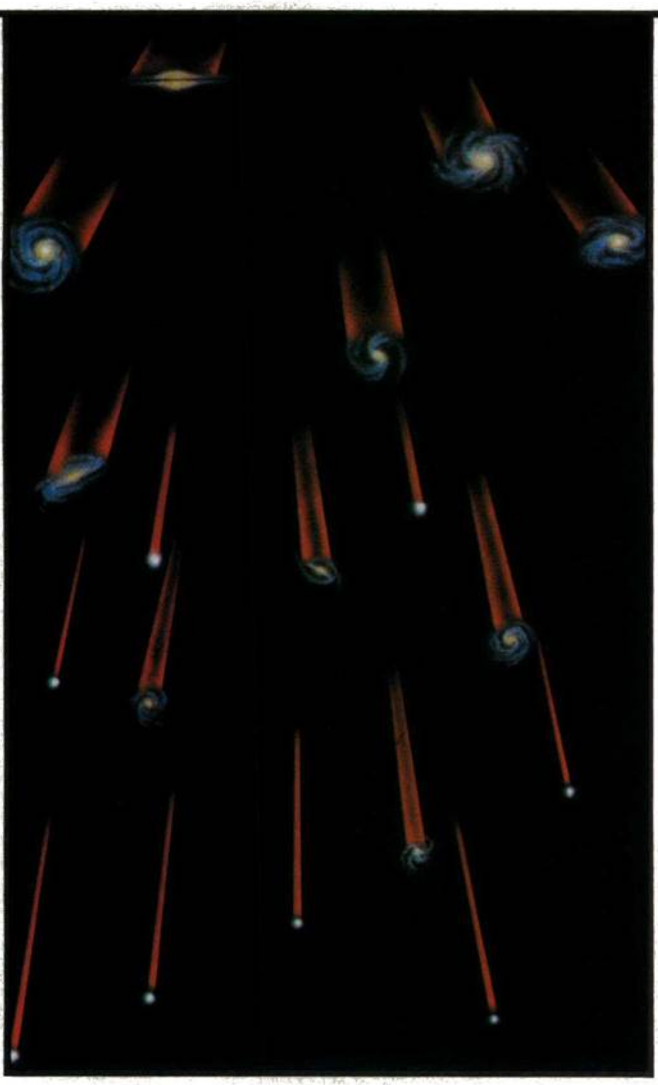
Carbon appears to be the only element able to form molecules of sufficient complexity to constitute a basis for life. But according to many physicists, carbon and oxygen could not exist at the same time if either the strong or the electromagnetic force changed strength slightly in either direction with respect to the other. In fact, if the strong nuclear force were only slightly weaker, multiproton nuclei could not hold together against the repulsive force of the like-charged protons — only hydrogen could exist in the universe. Changes in the strength of the electromagnetic force would block any conceivable kind of chemistry. Electromagnetic interactions bind electrons to nuclei, and any change here alters the ability of molecules to form and interact. No chemistry, no life.

Finally, the strength of the weak nuclear force determines whether or not supernova explosions can occur. If the weak force were slightly weaker, neutrinos would pass out of the star without interacting and could not blow it apart; if slightly stronger, neutrinos would be trapped in the star's core. Recall that it is the supernova explosion that produces elements heavier than iron and distributes them throughout the galaxy, making them available for subsequent star and planet formation.

*The Formation of Planets.* Complex life cannot form in the vast, highly rarefied clouds of gas and dust that exist between the stars — and stars themselves are not appropriate places for life. This leaves smaller, cooler bodies in orbit around stars as the only logical abodes of life.

In addition to all of the constraints associated with the formation of stars, further restrictions are necessary to allow planets to form. For instance, if the gravitational force were slightly stronger (or the electromagnetic force slightly weaker) the formation of planets, according to our present understanding of the process, would be impossible. Planets form by the accretion of dust and gas into progressively more massive clumps. As the protoplanetary clumps gain mass, their increased gravitational attraction makes further accretion easier. A stronger gravitational force would make accretion into a runaway

*In 1913, Vesto Slipher noticed that the spectra of galaxies seemed shifted toward the red end of the spectrum. Edwin Hubble interpreted this as a cosmological expansion. Today the recession of distant galaxies is believed to be the remnant of the explosive birth of the universe.*



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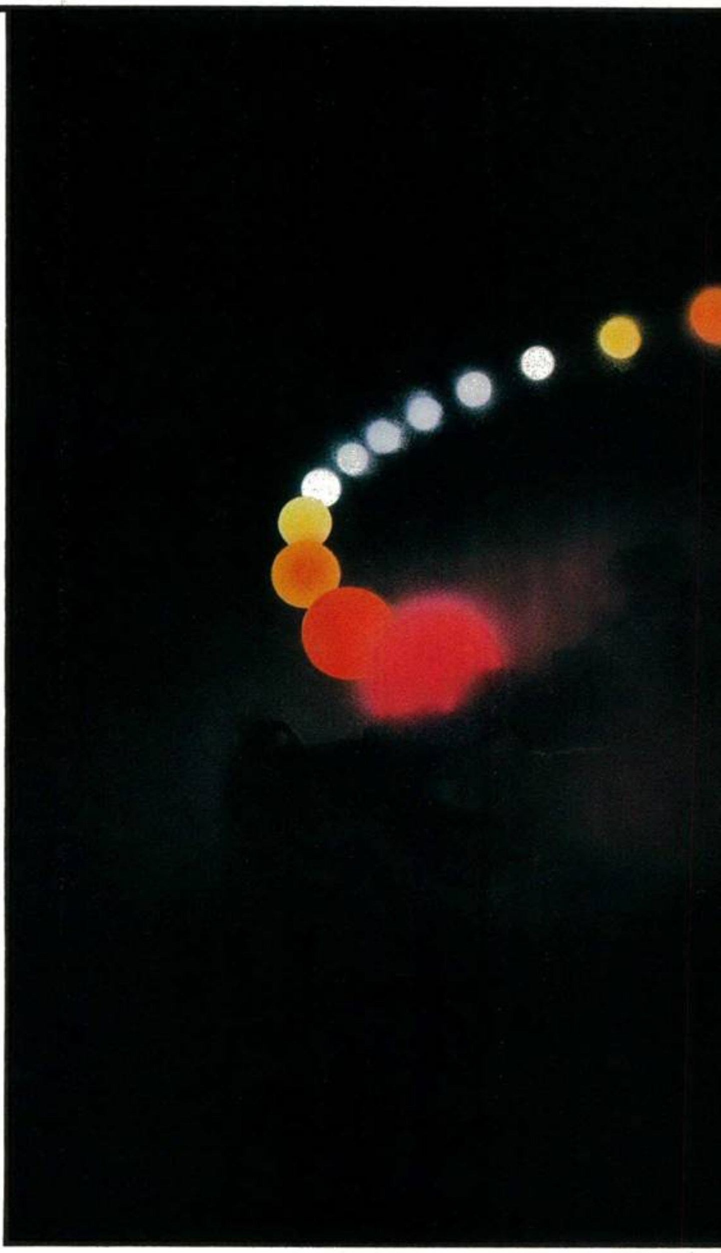
process that could lead only to stars. If the electromagnetic interaction were weaker, the original clumps of dust could not form because atoms would not easily join into the molecules that constitute the dust.

Life as we conceive it demands severe constraints on the initial conditions of the universe. Life and consciousness are not only the direct result of the initial conditions, but could only have resulted from a narrow range of initial conditions. It is not that changes in the initial conditions would have changed the character of life, but rather that any significant change in the initial conditions would have ruled out the possibility of life evolving later.

Why is the universe the way it is? If initial conditions had been different, the universe would have evolved as a lifeless, unconscious entity. Yet here we are, alive and aware, in a universe with just the right ingredients for our existence. How are we to interpret such a fortuitous state of affairs? Perhaps there are (or have been or will be) an infinite number of universes, each with its own combination of initial conditions, the overwhelming majority of which do not result in consciousness — stillborn universes.

The rate at which the universe expands is decreasing as a result of the gravitational attraction between clusters of galaxies. If the force of gravity is sufficient, the universe will eventually stop expanding and begin to collapse. The final collapse of our universe could result in the birth of the next universe, just as the birth of our universe may have resulted from the collapse of a previous universe. An infinite series of expansions and contractions, each possibly having its own set of initial conditions, is known as the oscillating universe theory. We could view each new universe as a new deal in a cosmic card game. We would then find ourselves in the only universe that by chance happened to have just the right initial conditions to produce life and consciousness — a cosmic royal flush.

Although the evidence is not conclusive, it now appears unlikely that there can be an infinite sequence of universes. So far, observational evidence indicates that our universe will expand forever, so there can be no



***The early universe contained only hydrogen and helium, so the first stars contained no heavy elements. The furnaces of these massive suns synthesized the elements up to iron: When they exploded as supernovae, the stars distributed the new elements into space — along with even heavier elements cooked in the explosion itself. Because of this interstellar pollution, subsequent stellar generations contained small quantities of elements heavier than helium. It also enabled at least one star to form planets.***

possibility of a new universe being born from its ashes. And even if the preliminary evidence is incorrect and our universe does eventually contract, our present understanding suggests that no expansion phase would follow the contraction. Thus we have both observational and theoretical arguments against the oscillating universe theory.

More likely than an infinite number of universes over time is an infinite number of coexisting universes — an infinite number of "hands" dealt simultaneously, with at least one of them having the "royal flush" combination that harbors life. An infinite number of infinitely large universes could exist simultaneously, each with no possibility of interacting with the others. This idea is not as far-fetched as it may seem.

Certain fundamental philosophical problems with quantum mechanics — the theory that explains the behavior of matter on the smallest scale — can be resolved by the existence of multiple universes. These philosophical difficulties stem from the fact that conventional quantum mechanics requires an "external observer." The problems become particularly acute when we attempt to apply quantum mechanics to the universe as a whole, since the concept of an external observer would become physically meaningless. The many-worlds theory of coexisting universes proposed by Princeton University physicist Hugh Everett provides an interpretation of conventional quantum mechanics that eliminates these problems while retaining the content of the conventional theory.

In quantum mechanics, several different outcomes are potentially possible from a given set of initial conditions. Imagine, for example, a collision between two electrons. Precise values of the positions and velocities of the particles have no objective meaning in quantum mechanics, so the end result of the collision cannot be determined until it is observed or measured. Although the *actual* outcome of an event cannot be predicted, we can determine the *probability* of the various outcomes. Certain results are more likely than others, but the collision has many possible outcomes. According to the many-worlds interpretation, the universe branches in such a way that each possibility becomes a reality in separate and distinct universes.

If there are an infinite number of universes in either space or time, "world ensembles" in the words of Cambridge University physicist Brandon Carter, then we have an explanation of the initial conditions of the universe. We, as conscious observers, naturally *must* find ourselves in that universe whose initial conditions were such that the existence of conscious observers is allowed. This explanation is ofter referred to as the "anthropic principle." Carter characterizes it by paraphrasing the French philosopher Rene Descartes: "*Cogito ergo mundus talis est*" (I think, therefore the world is as it is).

The anthropic principle is different in several ways from explanations usually encountered in science. For one thing, scientific explanation generally proceeds from the more fundamental to the more complex. The anthropic principle reverses that flow, using the more complex (our existence) to explain the more fundamental (the initial conditions of the universe).

Moreover, traditional scientific explanation proceeds from past to future. The anthropic principle reverses this too, deducing the past from the present. It uses a subsequent, rather than a prior, constraint — the initial conditions of the universe are restricted to those necessary for our presence as inquirers into the nature of the universe. Our existence severely, and perhaps uniquely, constrains the conditions present at the Big Bang.

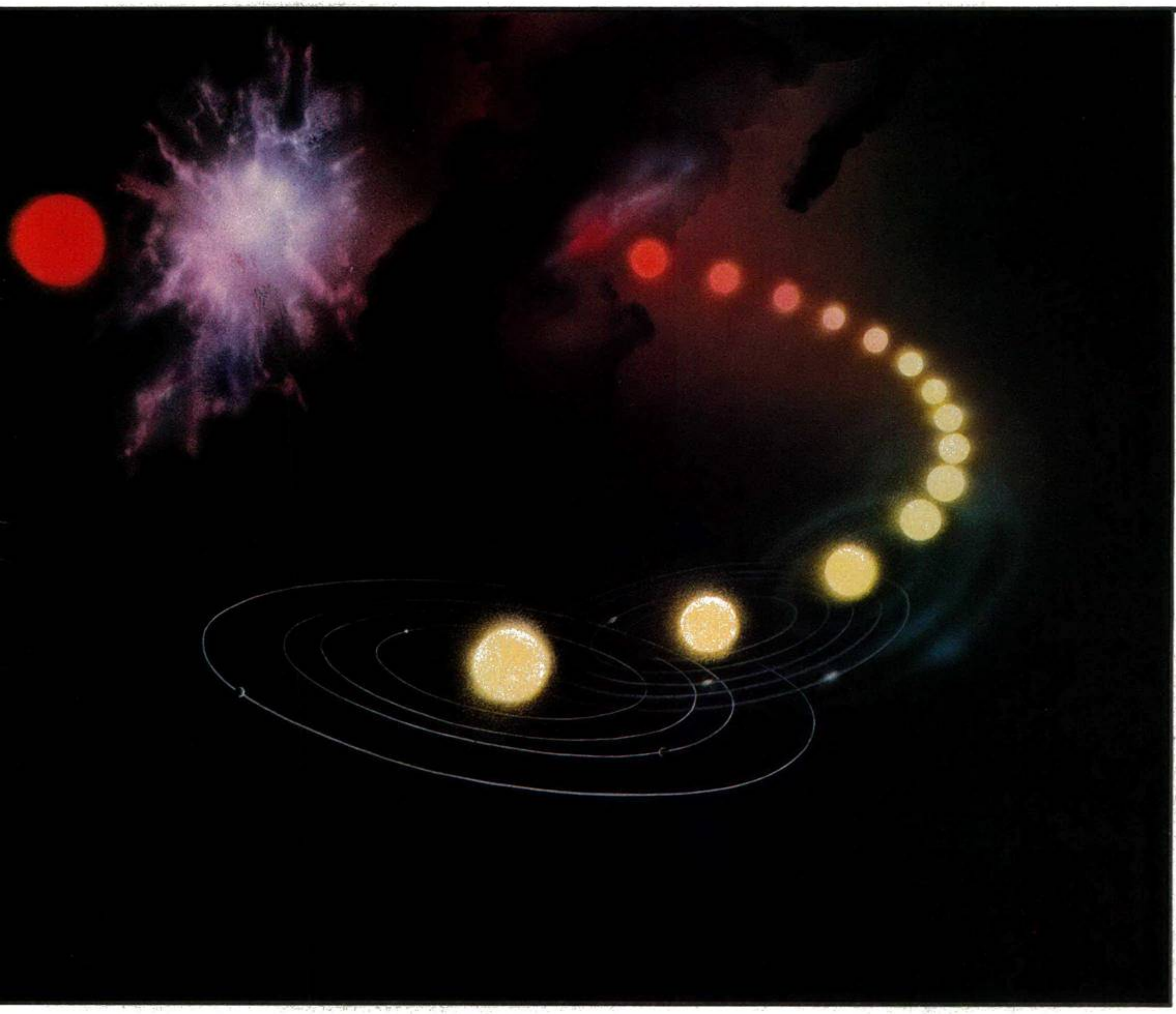
If the initial conditions responsible for the appearance of life in the universe are independent of each other, then there must be an infinite number of universes. It is almost unthinkable that, with any combination of initial conditions possible, the one universe that exists just happens to have the combination that allows conscious life. We know now, however, that the initial conditions are not all independent quantities.

Recent theoretical developments have shown that the weak nuclear and the electromagnetic forces are really different manifestations of the same force; it is just a matter of time until this unified theory also includes the strong nuclear force. Perhaps some day a single, grand unified physical theory will tie the initial conditions together into a neat package so that the relationships between them no longer seem arbitrary. When and if this happens, the argument for multiple universes will be weakened but not eliminated. We would still have to deal with the question of why the relationships dictated by physical theory just happen to be those that lead to consciousness. Again, the multiple universe theory suggests itself as the explanation of why the universe is the way it is.

There is, however, another explanation for our existence that does not require multiple universes. University of Texas physicist John Wheeler considers the possibility that no universe at all could come into being unless it were guaranteed to produce life, consciousness, and observers at some point in its "history-to-be." Wheeler speculates that only those initial conditions of the universe that guaranteed the existence of a future observer — us — could exist when the Big Bang occurred.

The thrust of Wheeler's argument centers on the role of the observer in defining "reality." He points to both the theory of quantum mechanics and recent experiments related to a famous "thought experiment" as possible indications of such a reversal of causality.

With the advent of quantum mechanics in the mid-



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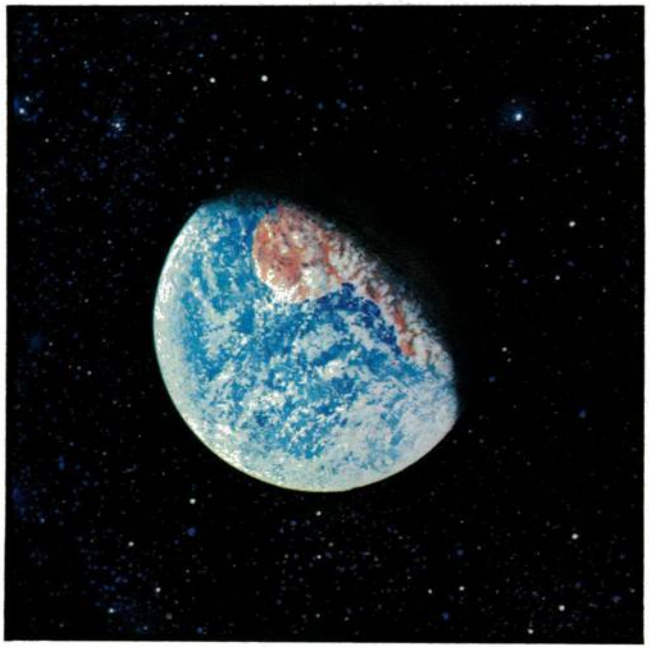

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and late 1920s, the physicist's concept of the nature of reality became drastically altered. Many physicists became convinced that such commonsense notions as attributing a well-defined position and speed to an elementary particle had no meaning. In fact, what we call the position or speed of an elementary particle represents only the possible outcome of a measurement, rather than a property of the particle itself. The measurement process itself seems to create the particle's position or speed.

This renunciation of reality in the intuitive sense of the word was as profoundly disturbing to Albert Einstein as it is to most people. In 1935, Einstein and two young colleagues, Boris Podolsky and Nathan Rosen, devised a thought experiment intended to demonstrate that the attribution of well-defined properties to elementary particles is meaningful even in the absence of measurement. It was an attempt to establish the truth of the more traditional view of reality.

The original Einstein-Podolsky-Rosen experiment was a thought experiment — an experiment that actually could not be carried out. By 1969, physicists devised a variation of this experiment that could be tested. Wheeler has focused on "delayed-choice" phenomena that can be tested by passing light or electrons through a narrow opening. If light passes through a single slit, it displays a pattern of symmetric bright and dark bands surrounding a broader central bright band — a diffraction pattern — when projected onto a screen. If light passes through two narrow slits set close together, the resulting image on a screen is an interference pattern — light and dark stripes where the electromagnetic waves have either added together or canceled each other out. Wheeler has devised experiments that allow an observer to decide which pattern he will observe while a photon or electron is in mid-flight, but after it has passed through either a single- or double-slit opening and is presumably committed to exhibit either a diffraction or an interference pattern. After the particle has passed through a given aperture (a single slit, say), Wheeler's results indicate that a last-minute free choice by the observer gives at will a double-slit or single-slit interference pattern.

This means, says Wheeler, that the past only exists as it is recorded in the present — it is senseless to talk of what the particle was doing before it was observed. This and other similar experiments have been carried out over the last decade, and the evidence is clear: the results are consistent with the predictions of quantum mechanics and are incompatible with predictions based on the arguments of Einstein and the "traditional realists."

The delayed-choice experiments essentially destroy our commonsense notions of reality. Not only do elementary particles not possess well-defined properties such as position or speed, but, worse yet, the experiments demonstrate that in a very real sense what one chooses to observe in the present defines what happened in the past! What we choose to measure, argues Wheeler, is really an inseparable part of a phenomenon that in earlier thinking one would have said has "already happened." To Wheeler, these results indicate that we, the observers, are somehow a participator in the Big Bang.

Through this strange coupling of future and past, observership becomes the mechanism of genesis. The observer is as essential to the creation of the universe as the universe is to the creation of the observer — in the absence of the observer there *is* no universe. We can scarcely imagine a more intimate connection between ourselves and the universe.

Whether or not Wheeler's ideas are correct, one thing is certain: the more we learn about the nature of the universe and of the natural miracle of our existence, the more we are filled with a sense of wonder and mystery. Science has displaced literal myths, but paradoxically it has confirmed their most significant message — the most mundane happenings are connected to the grandest cosmic events. In the words of the poet Ihab Hassan, "Unknowingly, we plow the dust of stars blown about us by the wind, and drink the universe in a glass of rain."

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*Mike Corwin is an Associate Professer of Physics at the University of North Carolina at Charlotte. He has also written* Twentieth Century Physics: Remodeling the Universe, *to be published by Holden-Day, San Francisco.*

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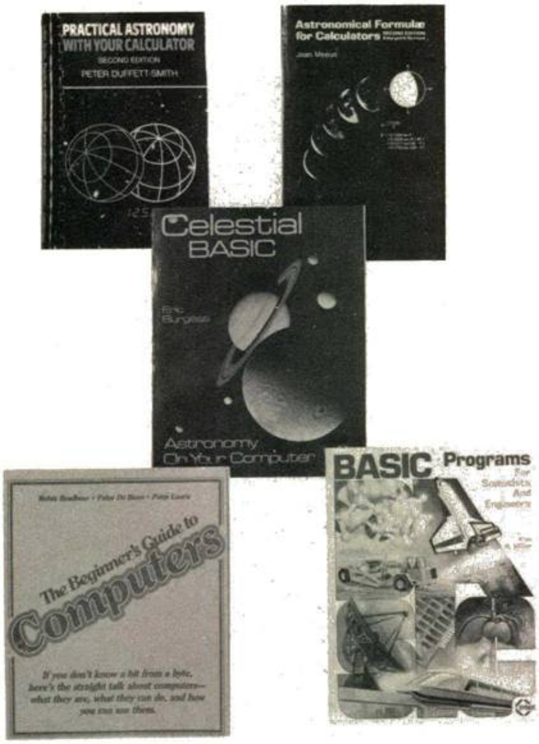
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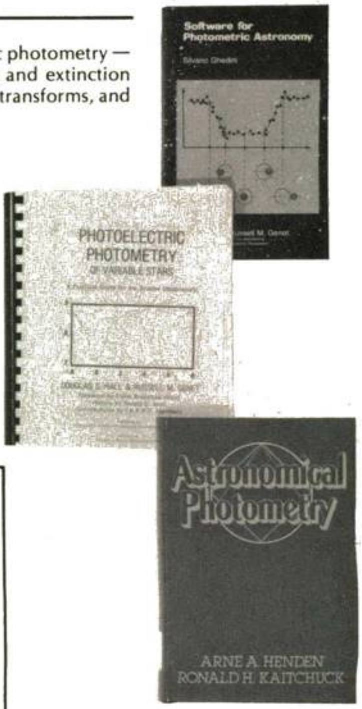
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# ASTRONOMY FORUM

## A Letter to Aspiring Astronomers

Every month the classified ad section of ASTRONOMY carries several requests from people asking for information on becoming a professional astronomer — how to do it, what's it like, what courses to take, and is it for me? It's evident that guidance counselors and other career-planning people haven't been able to provide the answers — but I will try.

First, who am I to talk? Starting with summer jobs after high school, I have worked professionally in astronomy for 12 years; and for the last five, I've worked as an astronomer full time. I haven't forgotten my roots — I started as an amateur, and I still get a thrill wandering around using the large observatory telescopes. It is exciting to make fruitful observations and to see an idea either demonstrated or shown to be wrong. I also enjoy visiting the open, scenic places where astronomy is done.

These are some of the good points of astronomy as a profession, but it has its bad points, too; and I'll emphasize them here because they are too rarely mentioned. Most amateurs already know the joy of astronomy — that's why you do it. But let me discuss some of the unmentioned realities of professional astronomy.

Most observatories are at high altitudes — so those thrilling nights at the telescope are usually cold. Only the largest telescopes are controlled from heated rooms, and most research does not require the use of these giants. Working through a 14-hour-long winter night can be very unpleasant in an unheated observatory dome, and as a professional astronomer, you usually won't have the option of quitting part-way through the night.

Weather can be frustrating to all astronomers. But while an amateur's observations can often be postponed, this is usually not true for the professionals. Heavy dew or strong winds can force closure of the dome. Clouds or equipment failure can wipe out a whole observing run, perhaps the only one assigned to you for the entire year. And even when it's clear, poor seeing can ruin high-resolution studies. Radio astronomy, though not hurt by clouds at some wavelengths, has its own related set of gremlins.

Then if you do get time on a big telescope, the fun of making the observations may be dampened somewhat. Why? You are not allowed to touch the telescope — only the trained night assistants are allowed to move them. The next generation of telescope will be even more removed — especially if the telescope is in orbit.

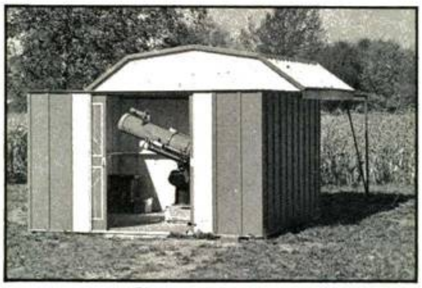

Photo and observatory by Howard Zeh

As a scientist, the astronomer's laboratory is the sky and out of his reach. This means you may have to wait for your experiment (event) to occur by itself. I once spent a month waiting for solar prominences of reasonable size to appear so that I could study them. It's not that there weren't any prominences; it's just that the visible type DS prominences were so small that they didn't satisfy my observational requirements. To fill the time, I worked on other observations or data reductions.

That's the next step. The cold hours spent at the telescope lead to many more hours — six to eight times more — reducing the data. So you learn to live with delayed satisfaction. From the excitement of making fruitful observations to the payoff — seeing an idea demonstrated or discredited — may take months. Or what you've observed may not be immediately explicable. You could spend days, weeks, or even months of analysis and cogitation without getting answers. Critical measurements, requiring hours of leaning to look through an eyepiece, may have to be made on a measuring engine. Reduced data and a sore back may result. Guiding the computer reduction of the data with a computer program that refuses to run properly is a hidden headache of astronomy.

Then begins the arduous task of interpreting and understanding the results, generating arguments to support your point of view, and writing it all up for a journal. After two or three internal and external reviews, it is scheduled for publication, perhaps a year after submission and two years after the observations were made.

There's a human side to astronomy, as well. Many professional astronomers are not amateurs any more. I still do amateur astronomy, but my interests have changed since I took up astronomy as a career. You can easily get overspecialized and lose interest in or time for other aspects of astronomy — and even for day-to-day living.

Backbiting and personal rivalries are as common in astronomy as in other professions. The redshift controversy is not a purely intellectual discussion — it has meant that some astronomers haven't spoken to each other in years. Disagreements over some aspects of planetary science started a long feud between other astronomers. And as in any work, making oneself unpopular

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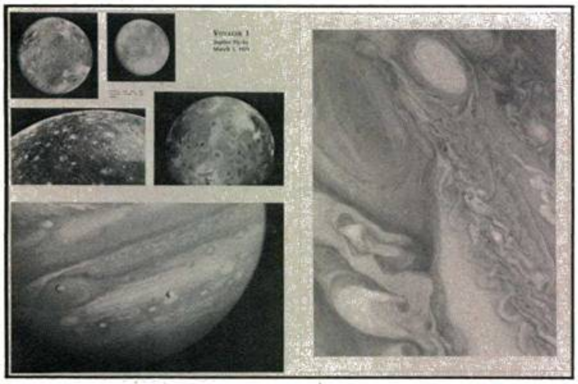

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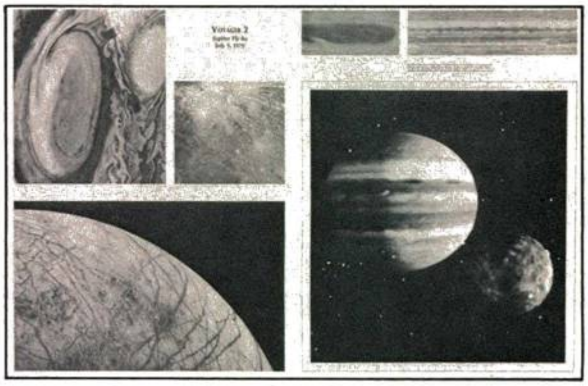

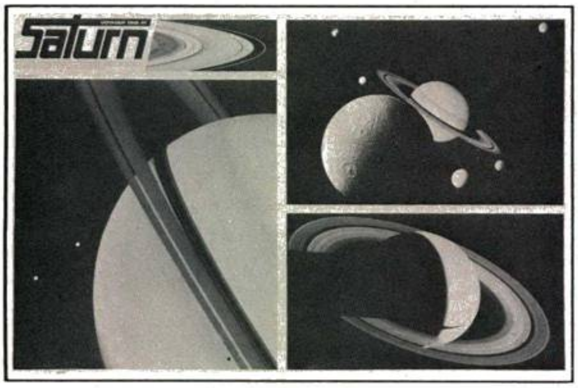

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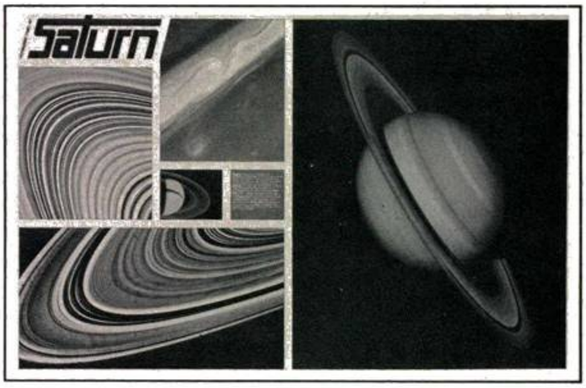

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or straying outside mainstream thought can affect allotments of telescope time, publishing of research, and the assignment of research money. And, speaking of money, astronomy is not a high-paying profession, nor is the current budget crunch helping salaries or the availability of jobs.

Astronomy also requires skills for human interaction. Your patience will be tried when you have to explain that you don't cast horoscopes and that astrology is poppycock. Many astronomers work for colleges and universities — if you have no desire to be a teacher, or at least a part-time teacher, your opportunities for employment will be limited. But even if you like teaching, teaching will divert time and energy you want to devote to research and may lead to "publish or perish" tenure worries. Worse than that, for a large fraction of your time, you will probably be hustling for research money for next year or explaining how this year's money was used, and with what results. Proposal and report writing are time-consuming.

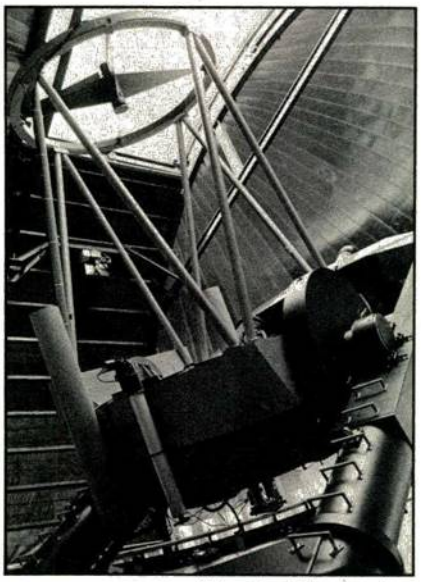
How do you get into the "astronomy business"? Curiosity about the universe, knowing how to ask answerable questions, and knowing how to approach those questions are important qualities in an astronomer. Persistence counts — persistence in working toward goals some years off, persistence in both research and in preparation. Today, a Ph.D. is nearly an absolute necessity in finding a job in astronomy, and a Ph.D. from a good university comes four to eight years after you get a Bachelor's degree.

But a Ph.D. is no job guarantee. Many young astronomers with Ph.D.s are not working in astronomy and, indeed, may have a hard time finding a job in another occupation since many employers think an astronomer can only do astronomy. I speak from experience. A Master's degree or Bachelor's degree in astronomy is almost worthless in terms of jobs, though there are a few exceptions. I am one of them: I have a Master's degree.

Much more than a knowledge of astronomy is necessary, too. You need a good background in physics for work in modern astronomy. Knowledge of computers or engineering will help your astronomy as well as supply a fall-back profession in hard times. Good writing skills will help you in communicating your research results to other astronomers and making your grant proposals more readable. This all pays off in getting recognition and funding for your work. Being at ease in public speaking makes teaching, research presentation at meetings, and public addresses much easier to live with. Finally, management and business skills help in proposal preparation and fund management if and when you receive a grant.

Working as an astronomer is not necessarily what a starry-eyed amateur may think it is. It obviously has its rewards — rewards that amateur astronomers already know. Those of us in professional astronomy wouldn't be there if we didn't know them, too. But everyone thinking of astronomy as a career should have an idea of what he or she is getting into.

One way to try astronomy on for size is to do some research before pursuing a career in it. It's a lot of fun, and when the excitement wears off, you'll find out whether you really want to do astronomy professionally. Many professional astronomers would be happy to have volunteer help with their research — or you can begin your own research program in some area. Variable star magnitude measurements, either visual or photoelectric, are a good "school," as are lunar and planetary occultation timings and astrometric observations of comets. Naturally, nova, supernova, and comet search programs can all use more data, and they all require careful preparation, observation, and sometimes tedious data reduction. Furthermore, they are all useful projects that can be done by an interested dedicated amateur.


University of Wyoming photo.

Are you prepared to follow established methods to do one or more of these research projects, or do you have the urge to take shortcuts? This is not to say that new methods shouldn't be invented to improve or replace established techniques, but you have to be able to prove the new one is better — not just to your own satisfaction, but to the satisfaction of other astronomers as well. Are you prepared to place your reputation on the line when you send in your results? — this is an especially important question to a professional.

Are your interests broad and varied enough (mine include meteors, the zodiacal light, comets, solar prominences and corona, and planetary occultations) to keep you busy with research if you get tired of one topic? If you're likely to run out of steam in a few years, it may not be worth the effort required to become a professional astronomer with the narrow range of expertise that usually comes with it.

There are many amateur astronomers who do professional-quality work and make important contributions, but who have other jobs during the day. You might find there is more satisfaction for you in this kind of life than in the life of a full-time astronomer.

If you are still gung-ho, think about going a bit off the beaten track. Consider solar physics, for example. Right now there are tenure-track positions available and going begging for the right people. Speaking as a converted night-time amateur astronomer, I can assure you that the Sun is a fascinating star. Although solar physics isn't fashionable or "sexy" right now, solar physics supplies fundamental data for explaining processes observed in stars, nebulae, and galaxies. Current studies may lead to revolutions in our understanding of particle physics and theories of gravitation.

— *Stephen J. Edberg*
Pasadena, CA

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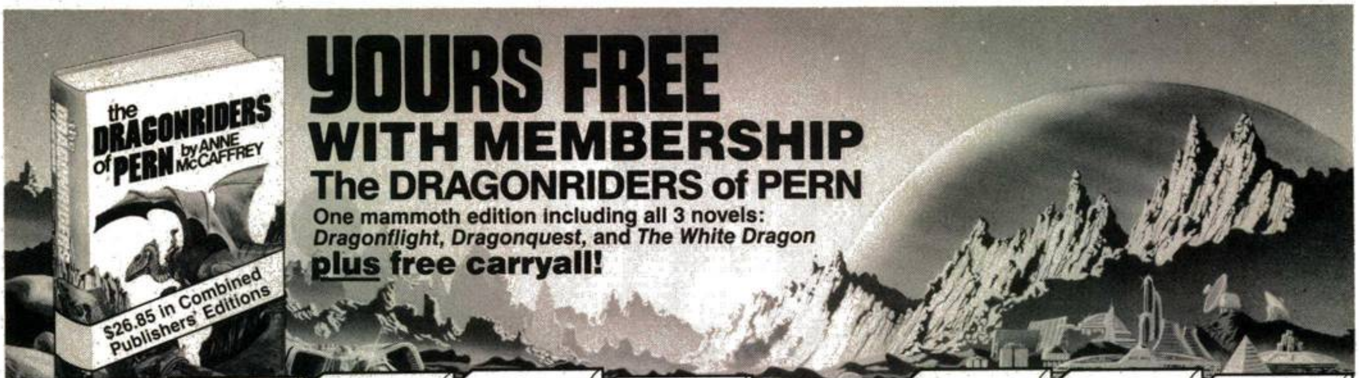
*Steve Edberg is a professional astronomer at the Jet Propulsion Laboratory in Pasadena, California. He is currently working on the International Halley Watch.*

**Information on Being an Astronomer**

Order a 25-cent pamphlet from the American Astronomical Society, 1717 Massachusetts Ave., N.W., Suite 603, Washington, DC 20036.

- "How to Become an Astronomer" by F.D. Miller, Sky Publishing, now out of print — but possibly available in libraries.
- *Contemporary Astronomy* (2nd ed.), a textbook by Jay Pasachoff, Saunders College Publishing, contains anecdotal sections describing "A Night At Palomar," "An Eclipse Expedition," "Observing with the IUE Spacecraft," and "At A Radio Observatory," as well as a good final chapter entitled "Astronomy Now."
- *Our Cosmic Universe* by J. Kraus, Cygnus-Quasar Books.
- *In Quest of Telescopes* by Martin Cohen, Sky Publishing.
- *Revealing the Universe* by J. Cornell and Alan P. Lightman, MIT Press.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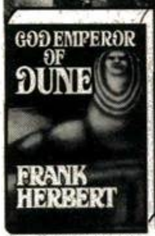
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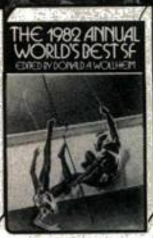
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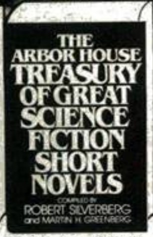
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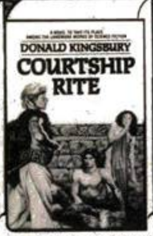
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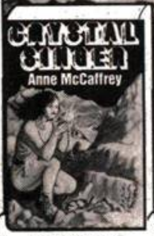
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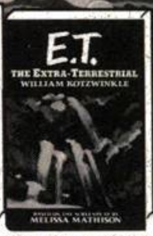
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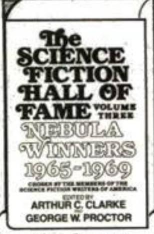
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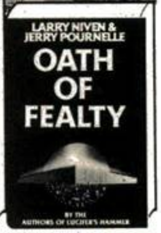
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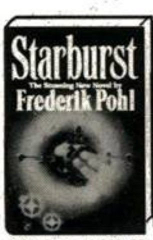
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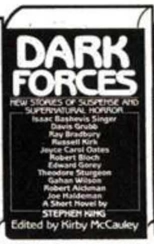
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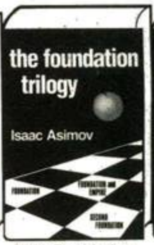
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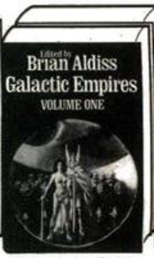
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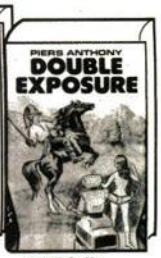
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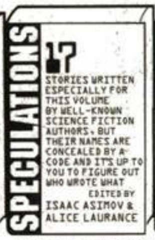
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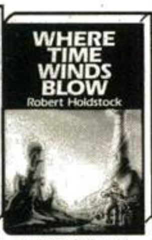
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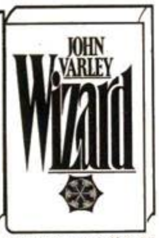
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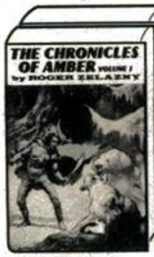
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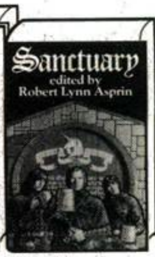
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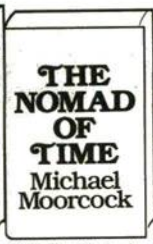
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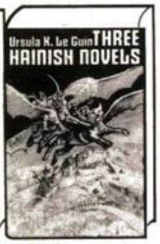
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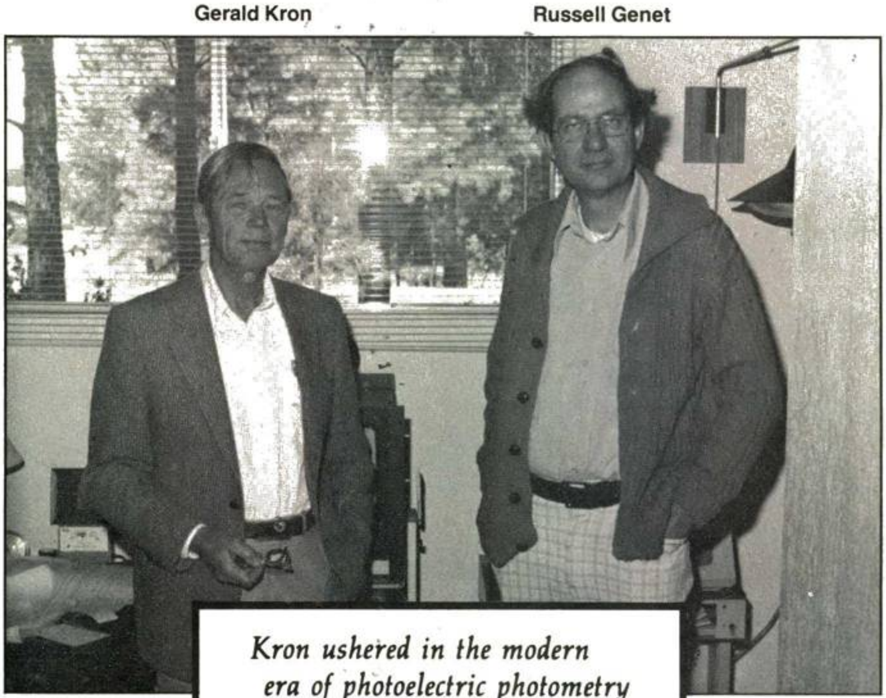
# Gerald Kron and the 1P21 Photomultiplier

From the beginning of photoelectric photometry in the late 1800s until just after World War II, photometers were expensive, unreliable, and difficult to use. Gerald Kron's use of the now classical combination of the inexpensive but extremely sensitive 1P21 photomultiplier tube, DC amplifier, and strip chart recorder made photometers relatively cheap, reliable, and easy to use. Within a few years, photoelectric measurements were being made at almost every professional observatory. Russell Genet interviewed Kron at the Pinecrest Observatory in Flagstaff, Arizona; from this interview comes the story of the first use of a 1P21 photomultiplier tube for astronomy.



*Kron ushered in the modern era of photoelectric photometry when he used the 1P21 photomultiplier tube at Lick Observatory immediately after WW II.*

ASTRO: When World War II broke out, how was it that you decided to go to MIT, and when did you first see a 1P21 photomultiplier tube?

Kron: I got a letter from A.E. Whitford, who was at MIT working on radar, suggesting that I come help — so I did. In a radio store in Boston I saw a 1P21 photomultiplier for $50 and bought it with money from a small fund obtained for the purpose by Joel Stebbins. I kept that 1P21 with me wherever I went. I worked with DC (direct current) amplifiers at MIT, and before I left there, I realized that the way to do photometry was with a DC amplifier and a recording meter, not with a galvanometer.

ASTRO: Did you actually build a DC amplifier at this time?

Kron: Yes. I built one on my own time in my room using parts I had gotten at various radio stores. The so-called "Kron amplifier" that appeared right after the war was based on this unit.

ASTRO: Why did you leave MIT?

Kron: The weather was terrible, and soon I had a cold. Horace Babcock, who also deplored Boston weather, asked if I would look into a war project at Caltech for both of us. With the help of Olin Wilson, Horace and I both obtained jobs at Caltech — back in our beloved California. After working at Caltech for a while, I went to the naval installation at Inyokern, California. There I was in charge of drafting, machine, optical, computing and electronics shops. Being a government-employed supervisor, I really didn't have much to do. This opened the door for work in the electronics shop on a DC amplifier that was serviceable enough so that I was able to assemble a photometer based on the photomultiplier once I got back to Lick Observatory.

ASTRO: How did you get the chart recorder?

Kron: That's an interesting story. To detect submarines during the war, they let a magnetometer down a cable from an airplane. In the airplane were electronic equipment and two strip chart recorders. Near the end of the war they called back all these airplanes and removed the equipment so the planes could go back to normal patrol duty. They were left with a big pile of chart recorders, and someone ordered them to be loaded on a barge and dumped at sea. Before this could be done, the electronic types who did the removals and who couldn't bear the thought of such destruction, loaded the recorders on the airplanes and flew up the west coast, dropping a few off at each naval installation. We got six of them at Inyokern. Security was not very tight — it's in the California desert — so the next time I went to Pasadena I just put a chart recorder, a defective one, in the trunk of my car along with the DC amplifier I'd built and another couple of 1P21 photomultipliers I had "acquired" at Inyokern.

ASTRO: So when the war ended you got married and went back to Lick Observatory?

Kron: Yes. I married Katherine Gordon, also an astronomer, in Pasadena, and the two of us, along with three 1P21s, a DC amplifier, and a chart recorder headed for Lick. I had a burning interest to try this all out. The 12-inch refractor was available, and with this new photoelectric equipment it became a very powerful instrument. We observed variable stars, eclipsing binaries and Cepheids.

ASTRO: In 1946 you wrote up your conclusions about doing photoelectric photometry with a 1P21, DC amplifier, and chart recorder and sent it off to the *Astrophysical Journal*?

Kron: Yes, and the editor showed it to Al Hiltner who was very enthusiastic about photoelectric photometry. Of course, Hiltner and many other astronomers had suspected that the 1P21 might be a good performer, but all of us were surpised by how well it actually worked.

ASTRO: Of course your 1946 paper is now viewed as a classic, and its publication marked the beginning of the modern period of astronomical photoelectric photometry. You went on to be the first to observe starspots photoelectrically and the first to observe flare stars photoelectrically. Then there was your development of the electronic camera, but that is another story.

*Russell M. Genet*
Fairborn Observatory
Fairborn, OH

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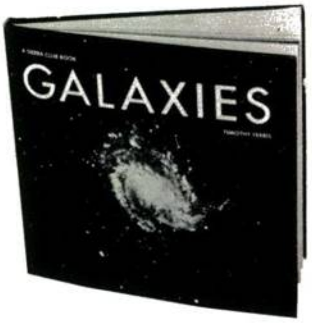
**by Timothy Ferris**



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# ASTRONOMY
# IN FOCUS

### Public Relations for NASA?

Sir / Reading your latest articles on the Space Shuttle leaves me feeling very confused. How can President Reagan stand at the landing of STS-4 and assure NASA that he looks forward to future programs, only to turn around and sign additional budget cuts for space research?

NASA needs a good public relations firm. They need to broadcast the advantages of space research and exploration all over radio, TV, magazines, and billboards, to illustrate the countless benefits that would result from continued funding of our space agency. A good public relations firm could also encourage wealthy corporations and individuals to contribute time and money toward NASA's efforts. Maybe then the President would realize that the knowledge, resources, and adventure that space offers are something that our nation must take advantage of.

Marcia Kuma
Buffalo, NY

### Faster Than a Speeding Photon

Sir / I enjoyed Jack Schendel's article "Looking Inside Quasars" (November 1982), but that isn't quite why I am writing. In the article was the generally accepted statement that "Einstein's theory of relativity expressly rules out the possibility that anything can go faster than light." Nothing unusual about that, until I read the article "Time Travel" in the September issue of *Science Digest*. The author of that article stated (p. 88) that Dr. Gerald Feinberg of Columbia University "points out that, contrary to popular belief, faster-than-light travel is *not* ruled out by the equations of special relativity. Only travel *at* the speed of light is forbidden." this was followed by a discussion on tachyons, those theoretical faster-than-light particles, and cosmic-ray showers, during which tachyons were thought to have been detected in 1973 by Drs. Roger Clay and Philip Crouch.

To an amateur this conflict of opinion presents a very interesting yet confusing situation. Does anyone really know what is hidden within Einstein's equations of relativity?

Robert B. Rieser
Houston, TX

*— Strictly speaking, relativity does not preclude faster-than-light travel — only motion at the velocity of light. Although some people have suggested that there are ways around the light-speed barrier without the necessity of passing through it, no one has the faintest idea of how this might be done. So far as physicists now know, the only way to go faster than light is to accelerate up to and beyond light-speed — and this is a physical impossibility according to relativity theory.*

### Film Loading Tips

Sir / Re: "Film Loading Tips," by Paul Roques, in the November issue:

There is a simple and easy method of removing a short piece of 35mm film from a camera, which I have used for years.

After taking your shots, wind off one or two more exposures, then open the camera back in complete darkness. Turn the camera over so that the cassette falls into your hand and then cut the film with a pair of scissors, about ¼ inch from the cassette. Using the cut end of the film, pull the exposed end of film from the camera for a new leader.

The short piece of film can be wound up and placed in a light-tight container for delivery to the processing lab, or wound into one of the inexpensive cassettes now on the market, or installed on the reel of a developing tank for home processing.

Practice with an old piece of film a few times, and make sure you have all the equipment available in the darkroom before turning off the lights.

Peter M. Preston
Brantford, Ontario

### Credit Where It's Due

Sir / I am flattered that the illustrations in my article ("Film Loading Tips," November) were credited to me, but alas, they are the product of Robert Klein — who consented to upgrade my crude sketches.

Paul Roques
Los Angeles, CA

### Hidden Doodles

Sir / What's that upside-down tiger face doing in Michael Carroll's imaginative painting of a planet orbiting a quasar in the November issue? I got a real kick out of it even though I don't know why it's there.

Walter J. Tatulinski
Cleveland, OH

*— Astronomical artists have a certain flair for hiding images here and there in their paintings. You were very keen-eyed to spot the tiger; did you know that other hidden images have appeared in past issues of ASTRONOMY as well?*

### Thinking Metric

Sir / Good work on sticking to the Metric System! It is so refreshing to see more and more use of it in everyday life these days. Once a person uses it, he's a convert for life.

Now, how about finishing the job by eliminating those damn miles in your monthly Star Dome?

Preston Q. Boomer
Felton, CA

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*miles helps newcomers to astronomy understand it better. Please note that we give this distance in kilometers in "Planetary Data" in the Backyard Astronomer.*

### One-Issue Voting

Sir / I have a question regarding "Pro-Space Politics" in last October's issue. Am I misreading him, or is Mr. Simons saying that we should choose to vote for candidates entirely on the basis of whether or not they are pro-space?

I believe strongly in the space program; I have written letters (some at ASTRONOMY's request) to the President, my congressmen, and most recently to George Keyworth, the President's science advisor, urging them to support many aspects of the space program. But I am not going to vote for someone who is pro-space and possibly anti-everything else.

This country is facing many economic and social problems. To ignore all of them and concentrate entirely on one important issue is like choosing a dentist because his chair is more comfortable than anyone else's — and ignoring the matter of how good a dentist he is.

In his article, Mr. Simons said we should "write them [the candidates] to find out their views on space exploration and astronomy" and then, when we get their answers, we will "be ready to make an informed decision." What about all their *other* views — such as inflation, unemployment, taxes, defense, and everything else we have thrown at us? Do all these disappear with a strong space program? Exploring a candidate's views on one subject alone is not enough to make an "informed decision." If that's Mr. Simons' idea of informed, I hope he never votes again.

I would rather vote for a person who will do a little good in many areas than one who will do a lot of good in one area and no good in most others. The only way we are going to get anyone to listen to our case for a strong space program is to present it with at least some sympathy for other programs and interests.

Richard J. Vesper
Marseilles, IL

### Yerkes Observatory

Sir / That article on Yerkes Observatory (ASTRONOMY, December 1982) brought back some good old memories of my stay in Williams Bay during the 50s; Mr. Bond did an excellent piece of writing. Further, the sharply detailed photographs were a delight, as were his sketches showing some instruments. And the Yerkes gargoyle was great!

I was an associate at Yerkes for some time, staying with astronomer George van Biesbroeck, who operated a boarding house with his wife. The Van Bies were solicitous not only for the welfare of their residents, but also for the chickadees and other birds outside, especially during the winter. It was a delight to tramp the trail daily to work during the four seasons of the year. One day, I noticed a wire that ran waist-high along a trail through the woods near the observatory buildings. I asked the Van Bies what the wire was for. They told me that many years before, Dr. Edwin Frost, that courageous blind astronomer, had used the trail to go to work.

It was good to see the 40-inch telescope kept up to date — even sporting a modern console around its tailpiece, along with the latest electronic devices. I note that the right ascension and declination handwheels have been removed, lending trim looks to the old refractor. As can be imagined, many changes and updatings have been carried on over the 25 years since the last time I was there.

I'm glad to see that the Yerkes people manage to turn out a lot of valuable research, in spite of the indifferent weather conditions in those northern latitudes. And, of course, they have access to fine installations in Texas and elsewhere. Yerkes Observatory continues, to this day, to be a valuable training school for astronomers.

Robert H. Weitbrecht
Redwood City, CA

### Ooops!

Atmospheric refraction does not cause the Moon to appear larger or redder near the horizon, as was stated on page 34 of the August 1982 issue. Rayleigh scattering in the Earth's atmosphere causes the color effects, and the apparent size change is a psychological effect.

behind
the scenes

## low tech — high tech

*". . . the astronomer climbed the ladder to a high metal gallery, waiting for the front of the huge telescope to swing over, then opened the gate and gingerly lowered himself into the prime focus cage. Carrying the astronomer, the telescope slewed toward the spot where the night's first object lay.*

*"Peering into the eyepiece, he announced 'Okay, I've got it in the field,' over the intercom to the night assistant far below. He reached into a small metal box, pulled out his pad of paper and pencil, and with delicate strokes, began sketching the galaxy."*

Improbable? Certainly. Yet it wasn't so long ago that sketching was the only way to record what was seen — and the discipline of sketching made those visual observers some of the best "lookers" the world has ever seen. A sheet of blank paper presents an ultimatum to prove you know how to see. There are no excuses, no facile, "I already looked at M-42 tonight." Your sketch shows how much you really saw — how much data your eyes took in and your brain perceived — recorded on paper.

Don't worry about how your drawing looks — concentrate on seeing and let the other stuff take care of itself. Back in high school, I spent an awful lot of time pushing a pencil, drawing the Messier list with my 6-inch telescope and a few years later again with my 12-inch — and I know that that's when I learned to see things clearly.

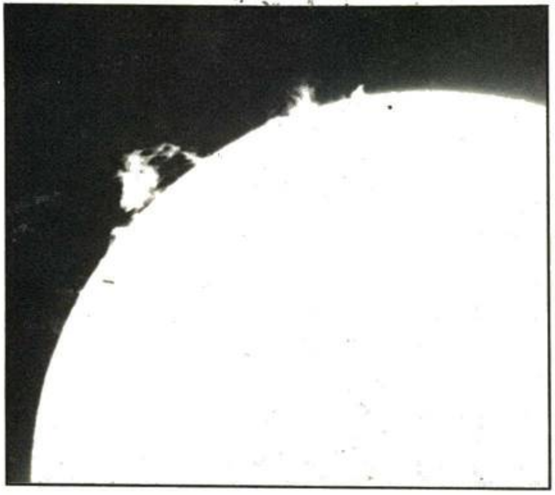
I also learned the value of making precise measurements. My first photometer used a photoresistor — a solid-state device barely good enough to detect the light of Jupiter with my 6-inch telescope. The only thing bright enough to measure was the Moon — so I measured the brightness of lunar phases and eclipses of the Moon. Today's equipment means that anyone with a good telescope can make important observations, observations that are in demand.

Although one approach is "high-tech" and the other is "low-tech," they are fundamentally the same. Both require that you stick with it, and both yield generous rewards in satisfaction.

Sincerely,

Richard Berry

Richard Berry
Editor



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gazer's
gazette

# capturing deep-sky objects on paper

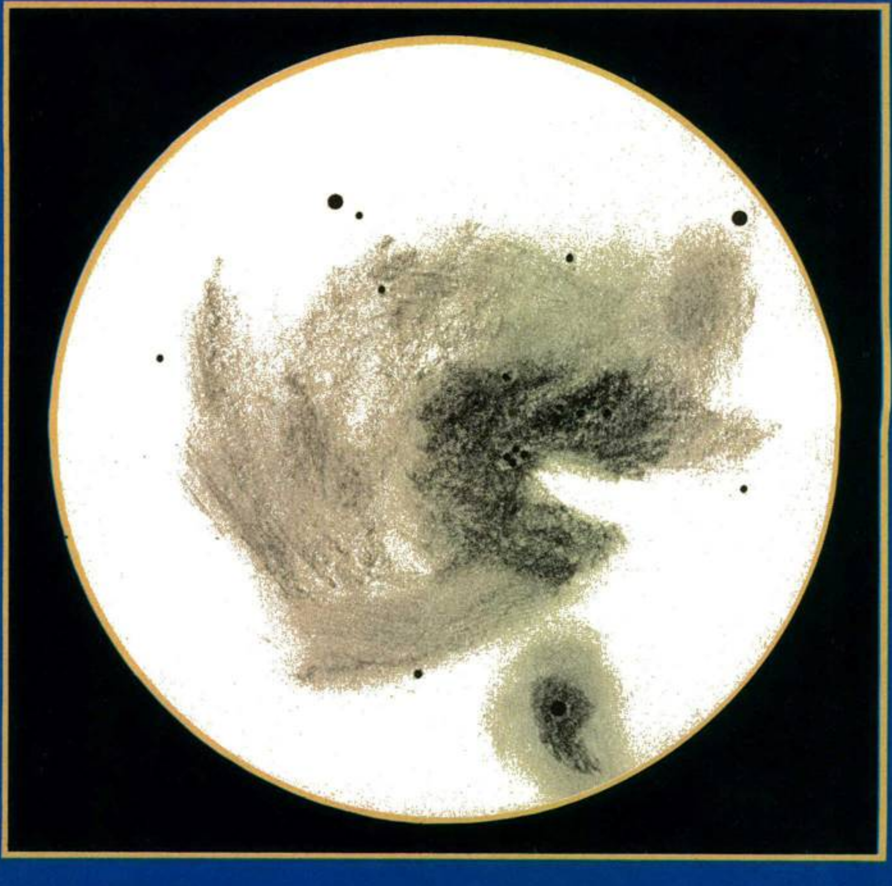
When you first looked through a telescope, you probably saw the Moon or a bright planet like Saturn, Jupiter, or Mars. Wasn't it a thrilling experience? It probably got you interested in further astronomical observing; the first time I saw Saturn through a friend's 4¼-inch reflector, I was hooked. But some observers "burn out" after that initial enthusiasm; what can you look at other than the Moon, eight planets, a few asteroids, and an occasional comet?

Fortunately, there are many alternatives. Deep-sky objects comprise the overwhelming majority of potential targets for your telescope: the *Revised New General Catalogue* contains about 8,025 clusters, nebulae, and galaxies, all of which are within reach of moderately sized (6" to 12") instruments. There are also several thousand double and variable stars that are easily observable with such telescopes.

So there is much to observe. But how should you go about observing deep-sky objects? What can you do to help yourself become a better observer and familiarize yourself with different types of objects? One of the most useful methods is to record your observations with pencil sketches. The suggestion may sound ridiculous in this high-tech era, when photometers, specialized cameras, image tubes, and tri-color photography are commonplace — and for professionals, sketches *would* be foolish. The era of great visual observers like the Herschels, Messier, Smyth, Rosse, Barnard, Bond, and Lowell is gone.

But does that mean that recording sky objects visually is a worthless practice? Certainly not. Many practical benefits arise from making sketches of far-away stars, clusters, nebulae, and galaxies. The most important is the pure observing experience you'll get out of it. Sketching makes you observe critically. It's the finest way to become acquainted with different classes of objects; by sketching them, you'll see how nebulae differ from galaxies, how open clusters differ from globulars. You won't "just look." Instead, you'll trace out spiral arms and dust lanes in galaxies, discern the distribution of stars in globulars, observe how galactic nuclei differ in size, shape, and brightness, spot central stars in planetary nebulae, and see how delicate nebulosity wraps in and around bright young blue stars. You might even record on paper a supernova in a distant galaxy. By forcing you to observe with a critical eye, sketching will make you a better observer.

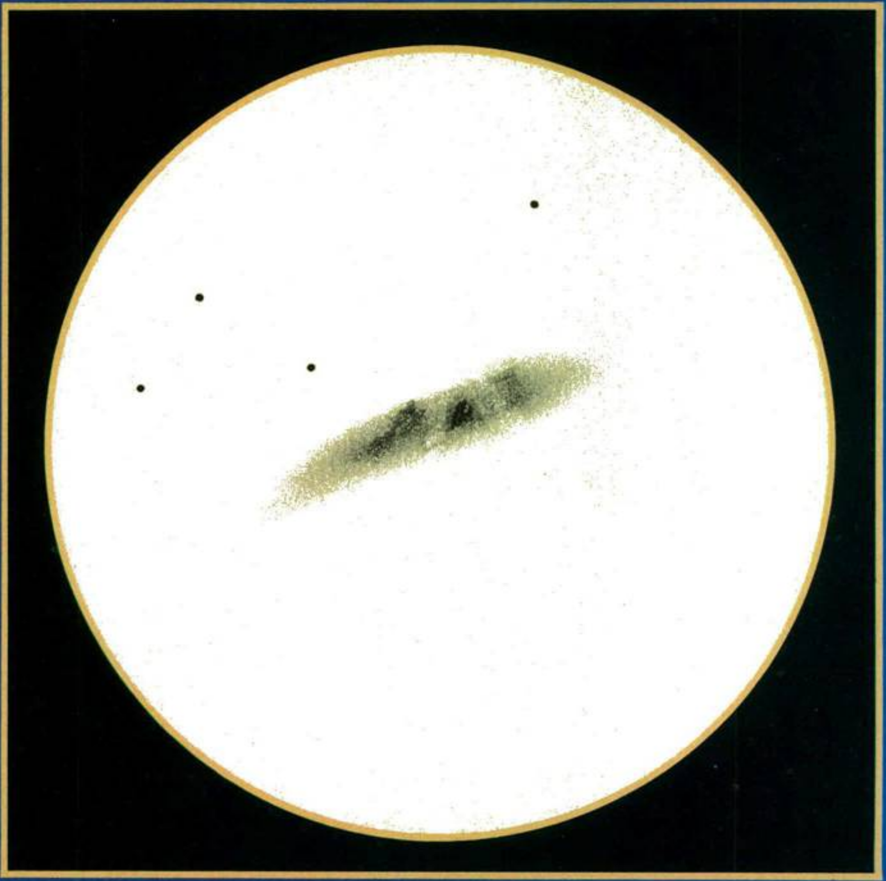
Some observers ask how sketching can be more useful than photography. Deep-sky photography is great for those who wish to make pictures of the sky. It's quite easy to do nowadays; just get a telescope, mounting, guider, and drive corrector, and with some practice you can turn out acceptable deep-sky photos. But photography isn't as much of a learning experience: when you take a deep-sky photo, you look through the focuser for a few seconds, open the shutter and guide



**Delicate shades and twisting nebulosity highlight backyard-telescope views of the Great Orion Nebula. This sketch approximates the appearance of M-42 in an 8-inch reflector at 80x. All sketches in this article are by the author and, unless noted otherwise, were made with an Ebony pencil and rub-down dots.**

## materials for sketching

All you need to sketch are a few inexpensive materials; you can find them at art or stationery stores. First you'll need a **compass** — $5 to $25 — or a **circle template,**which costs about $4, for drawing field-of-view circles. To make standard sketches of black stars on white backgrounds, you'll need the following: a pad of **smooth white paper** to draw on, which costs about $4 for one hundred 8½" x 11" sheets; a **black fine-tipped pen** for drawing stars, which costs about $1; and an **Ebony pencil** for drawing nebulosity, which costs about 25¢. If you want to make white-on-black sketches, you'll need **black paper**, which costs about $1 for a 19½" x 25½" sheet or **black cardboard**, which runs about $2 per similar-size sheet. You'll also need a **white charcoal pencil**, which will cost about 50¢. So your total cost will be around $10 either way you go, and these materials will last for some time. If you want to get a little fancy, you can get **neutral pH paper** sketchpads that won't yellow after several years due to acids in the paper; they don't cost much more than regular sketchpads. You can also get preprinted **rub-down dots** or "bullets" for very sharp stellar images. They cost about $7 per sheet, but several hundred come on a sheet. If you want to protect your sketches, you can get **clear spray lacquer** for about $5 a can.



**M-82 is an irregular galaxy in Ursa Major. Fine detail such as knotty bright patches and obscuring dust lanes are visible in it with medium-sized instruments. This drawing shows the view in an 8-inch scope at 170x.**

on some star. And you probably don't *study* the object — you just *look* at the picture. Furthermore, sketching is far less expensive than photography; all you need is a notepad, a couple of pencils, and clear skies.

Sketching is really easy: set up your telescope some night, just as you always do, but take with you a red flashlight and some sheets of smooth white paper that have comfortably large — say 3-inch — circles drawn on them in black ink. Once you've found a favorite familiar object, choose the eyepiece that shows the object best, get your pencil ready, and start to draw what you see. Sketch *lightly*. It's easy to get ambitious and rub a lot of graphite onto paper, smear it around and come out with a black, shiny mess. Be careful with proportions. First draw in the brighest stars — especially those near the center of the field and ones near the edge — and then carefully fill in star patterns so that all of the stars in the field are represented on paper.

As you draw stars, make sure that their magnitudes are fairly accurately represented; make the faintest stars tiny dots and the brighter ones slightly larger. It'll save a good sketch from ruin if you *don't* draw the stars *involved in nebulosity until* you draw the nebulosity — that way you won't smear pencil all over the stars. After plotting the field stars, take a black art pencil — I use an Eberhard Faber "Ebony" pencil — and rub some graphite down onto the paper where the nebulosity is in the field. You can then use your finger to smear it around a little to create gray tones and the illusion of nebulosity. Where you want to darken the nebulosity, slightly wet your finger and rub a little more. If you have to, use an eraser to correct mistakes, shape the nebulosity, or create dark lanes or other special features that exist in some deep-sky objects.

## deep-sky slides

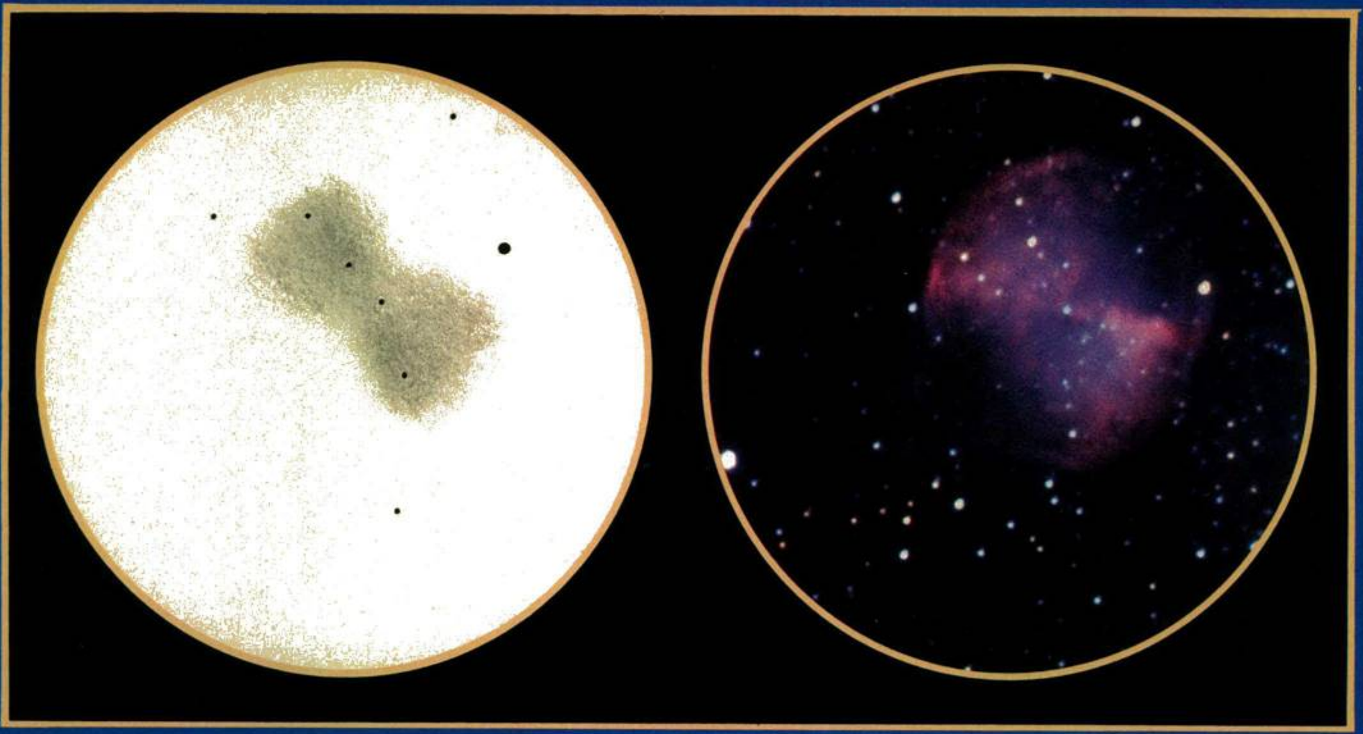
Making sketches of your favorite deep-sky objects opens up new possibilities for slide shows at astronomy club meetings or simply in your living room. You can make beautiful slides from your black-on-white sketches — slides that will show white stars on a black background — by photographing the sketches on a contrasty high-resolution black and white film. It's simple: set up a 35mm camera loaded with Technical Pan 2415 film on a sturdy tripod. Make a copy stand by vertically hanging the sketch you wish to photograph and illuminate it with two lights angled at 45°, one on each side. Set the meter, take the picture, develop the film, and *voila*! The negative will make a fine deep-sky slide to delight your friends.

You don't have to make a finished sketch at the eyepiece — make a rough sketch outside and take your time later indoors to finish and clean-up the sketch. If you do this, however, you must be honest: become familiar with the object and take everything down in rough form at the telescope; otherwise you might exaggerate the view and come away with a phony sketch. Draw only what you see — not what a photo told you to expect — then check the finished drawing against the real thing on another night. Preprinted rub-down dots that come in many sizes are a convenience for finishing sketches; they are expensive but guarantee that your stars are precise tiny points.

Most observers' sketches are "negatives" showing black stars on a white background. But you can also create more true-to-life impressions by using black cardboard and a white art pencil. This is trickier than black-on-white sketching, but with practice you can produce surprisingly realistic results. You can also create nice white-on-black slides by photographing (on black and white film) regular pencil drawings and mounting the negatives in slide holders.

The key to producing good eyepiece drawings is experience. Your first attempts may not look impressive, but they'll get better as you draw more and more of them. Save your first attempts: they may not be pretty or accurate, but later they'll let you see how you've progressed.

Some deep-sky objects are easier to draw than others. Double stars, for example, are relatively easy. All you have



**Under very dark skies, backyard telescopes compare favorably with long-exposure photographs for some objects. At left is a sketch of the Dumbbell Nebula in Vulpecula made with an 8-inch telescope at 170x; at right is an 80-minute exposure on hypersensitized Ektachrome 200, made by Ben Mayer with a 14-inch f/11 Schmidt-Cassegrain. Not as much faint nebulosity — and practically no color — is visible through the eyepiece, but M-27's dumbbell shape, its central star, some foreground stars projected onto the nebula's face, and subtle gradations in the nebula are visible.**

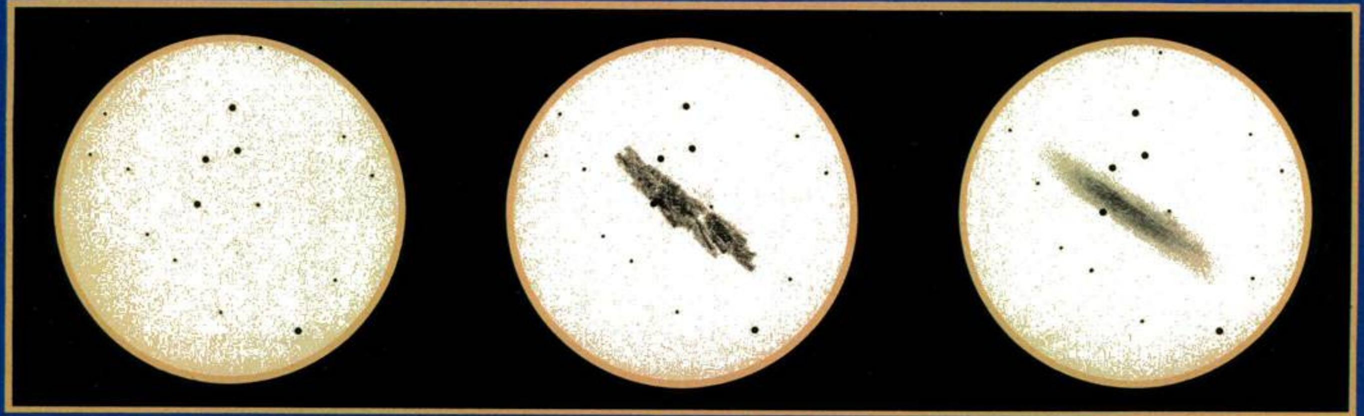
to do to sketch a double or multiple star is draw a starfield without any nebulosity. Make sure that you don't go wild on bright stars by drawing them as huge disks with sharp spikes sticking out of them. Try to keep the stars as small as possible, while still differentiating between magnitudes. Doubles like Albireo and Mizar are straightforward, roughly equal pairs; unequal duos like Sirius and Polaris are only slightly harder to draw. Double stars are a good training ground for deep-sky sketching.

Open star clusters are still just stars — no intricate fuzzy patches of light — but they are difficult to sketch because of the sheer number of stars involved. To make an accurate sketch of the Double Cluster or M-7, you could easily spend two or three hours glued to the eyepiece. It's no surprise that there are very few good sketches of open star clusters; if you decide to sketch an open cluster, be ready to spend a lot of time on it.

Globular clusters are actually a little easier although they contain more stars, because even in large backyard telescopes most of them aren't well resolved. When sketching globulars, reverse the normal method by putting down some pencil marks on paper and smearing them to create the "disk" of the cluster before plotting stars. Then draw lots of stars around the disk to re-create the view in the eyepiece. It's impossible to be one hundred percent honest in sketching globulars by drawing every little star at its exact position. You'll have to mottle the area with dots to fashion a realistic overall image of the cluster. Some globulars are easier to sketch than others, depending on their degree of concentration. Clusters like M-3 and M-15 are fairly easy, while looser clusters like Omega Centauri and M-22 take more time since you really see more individual stars over the face of the cluster.

Planetary nebulae are even more varied in appearance. Some are easy to draw because they are simple and fairly symmetric, like the Ring Nebula and NGC-3132. Others, like the Dumbbell and the Helix, are more difficult because of their complexity. As you start to sketch nebulae that are extended, you'll run into areas of varied surface brightness — different parts of a nebula are brighter than other parts. So you'll have to shade

**After some initial practice, it's easy to sketch deep-sky objects. This sequence of the galaxy NGC-253 illustrates a sketch in progress. Stars are first plotted, then pencil graphite is rubbed down onto the paper, and finally the graphite is gently smeared to create the illusion of nebulosity.**



## Selected Objects for Sketching

| type | object | r.a. (1950) | dec. | con. | mag. | size/sep. | rating |
|---|---|---|---|---|---|---|---|
| §S | The Andromeda Galaxy (M-31) | 00h40m | +40°00′ | And | 4.8 | 160′x35′ | d |
| ■ | NGC-246 | 00h45m | –12°09′ | Cet | 8.5 | 4′x3′ | m |
| §S | M-33 | 01h31m | +30°24′ | Tri | 6.7 | 65′x35′ | d |
| ★$^2$ | Polaris (α UMi) | 01h49m | +89°02′ | UMi | 2.0+9.0 | 18.3″ | e |
| ☐E | The Orion Nebula (M-42) | 05h33m | –05°25′ | Ori | 4.0 | 66′x60′ | d |
| ★$^2$ | Sirius (α CMa) | 06h43m | –16°39′ | CMa | –1.6+8.0 | 10.3″ | e |
| ★$^2$ | Mizar (ζ UMa) | 13h22m | +55°11′ | UMa | 2.1+4.2 | 14.5″ | e |
| ● | ω Centauri | 13h24m | –47°03′ | Cen | 5.0 | 23′ | d |
| §S | The Whirlpool Galaxy (M-51) | 13h28m | +47°27′ | CVn | 8.1 | 10′x6′ | d |
| ● | The Hercules Cluster (M-13) | 16h40m | +36°33′ | Her | 5.7 | 10′ | m |
| ○ | NGC-6231 | 16h51m | –41°43′ | Sco | 6.0 | 15′ | m |
| ○ | The Butterfly Cluster (M-6) | 17h37m | –32°11′ | Sco | 5.3 | 25′ | d |
| ☐ER | The Trifid Nebula (M-20) | 18h00m | –23°02′ | Sgr | 9.0 | 29′x27′ | d |
| ● | M-22 | 18h33m | –23°58′ | Sgr | 5.9 | 17′ | m |
| ○ | The Wild Duck Cluster (M-11) | 18h48m | –06°20′ | Sct | 6.3 | 10′ | d |
| ● | The Ring Nebula (M-57) | 18h52m | +32°58′ | Lyr | 9.3 | 1.5′x1′ | e |
| ■ | The Dumbbell Nebula (M-27) | 20h00m | +33°23′ | Vul | 7.6 | 8′x4′ | d |
| ☐S | The Veil Nebula (NGC-6960,6992-5) | 20h50m | +31°00′ | Cyg | 12.0 | 70′x6′,78′x8′ | d |

Rating system: e = easy to sketch; m = moderately difficult; d = difficult to sketch

★$^2$ double star
○ open cluster
● globular cluster
■ planetary nebula
☐E emission nebula
☐R reflection nebula
☐ER emission and reflection region
☐S supernova remnant
§S spiral galaxy

heavily in appropriate regions and lightly in others.

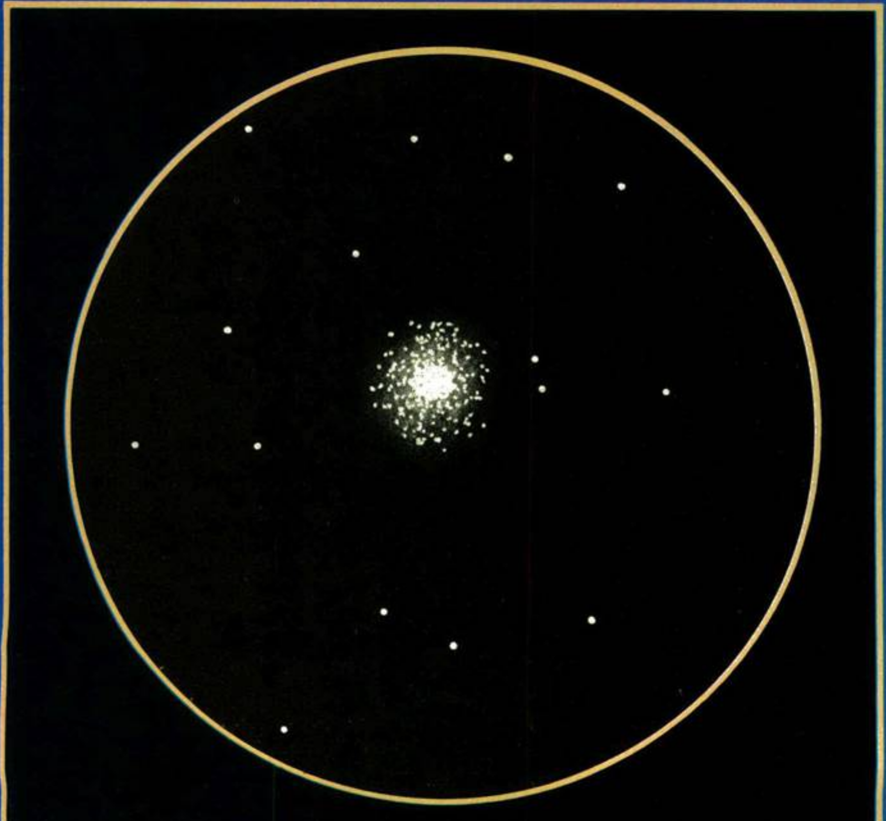
Most gaseous nebulae other than planetaries are very difficult to record on paper. Probably the most asymmetrical and diverse group of objects, they include HII emission regions, reflection nebulae, and supernova remnants. Their gas is often thrown out or twirled helter-skelter; it is generally so dim that only "thick" parts of it and areas near hot stars are visible. Telescope aperture plays an important role in the difficulty of sketching faint extended objects. In a 4-inch the Orion Nebula is easy to sketch; in a 20-inch it's practically impossible because there's too much to draw. Another complicating factor is that most emission regions are associated with open star clusters, significantly adding to your sketching time, no matter how big your telescope is.

Galaxies can be easy to sketch, but only if they're little puffballs that are far, far away. Members of the Local Group and other relatively close galaxies — especially spirals — are difficult. Spirals are invariably tilted at all kinds of crazy angles with respect to our line of sight, so they are almost all different in the eyepiece. Big, close galaxies like the Andromeda Galaxy and M-33 are easy to draw in small scopes, but really tough in large ones because they show internal detail like spiral arms, dust lanes, knotty patches, and even globular clusters. Most galaxies — objects like the Blackeye, the Sombrero, and the Whirlpool — are difficult but not too troublesome after you've practiced sketching.

Sketching deep-sky objects at your telescope is an inexpensive, relaxing, fun way to get to know the universe. It requires no electricity, film, drive, camera, or long setup time — just a sharp eye. You have the opportunity to go out and look at what's happening in the rest of the galaxy and universe, think about what you've seen, and easily record it to study indoors. It's the best bargain in backyard astronomy, and you can start taking advantage of it on the next clear night.

*—David J. Eicher*

**By photographing your sketches onto high-contrast fine grain film, you can make good white-on-black slides of your eyepiece views. This rendering of globular M-22 made with an 8-inch scope at 100x shows its large hazy halo, dense star-cluttered core, and the peripheral breakup of clustered stars. This sketch was made with pencil, rub-down dots, and a fine black felt-tipped pen for the cluster stars.**



# ASTRONOMY
# REVIEWS

**Voyages to Saturn**
David Morrison
227 pages, paperback, $9.50
NASA SP-451 (1982)
[order from U.S. Government Printing Office, Washington, DC 20402]

If organizations like the Planetary Society had their way, much more of the space program's money would be spent on unmanned exploration of the planets. And although this approach is sometimes dismissed as self-serving, there is more than ample evidence that unmanned robot spacecraft can return immense quantities of data for comparatively little expense. Pioneer, Mariner, Viking, Voyager — all these probes obtained information about Mars, Venus, Jupiter, Saturn, and interplanetary space that went far beyond the conservative expectations of their designers.

*Voyages to Saturn* chronicles the journey of the two unmanned Voyager spacecraft to Saturn. David Morrison is a member of the imaging team that brought us those spectacular photographs of Saturn and, before that, of Jupiter. His insights and anecdotes about the day-by-day happenings at the Jet Propulsion Laboratory, especially during the Saturn encounters, add a nice personal touch to the book.

There are two major themes in *Voyages to Saturn*. The first deals with our knowledge of the giant ringed planet. Morrison opens the book with an historical overview that describes mankind's growing understanding of Saturn from the first confusing observations with early telescopes to the pathfinding Pioneer 11 Saturn probe in 1979. But despite Pioneer's successes, it was not until the Voyager 1 and 2 encounters with Saturn that we gained a real appreciation for the complexity of the planet, its moons, and its innumerable rings.

The second focus of the book is on the Voyager spacecraft and mission. In the late 1960s, NASA scientists first began work on the "Outer Planets Grand Tour" — an ambitious and expensive program that was to send four unmanned probes to explore Jupiter, Saturn, Uranus, Neptune, and Pluto. Budget cuts pared down the initial plans to what became the less ambitious but still impressive Voyager program. Described as the "most sophisticated robots ever to explore other worlds," the two Voyager spacecraft were designed for encounters of Jupiter and Saturn. Calculations also showed that, depending on what options were taken at Saturn, one or both craft might be sent on to Uranus and perhaps Neptune.

Though launched perfectly, both spacecraft experienced various systems failures and malfunctions, which could have ultimately resulted in curtailing or aborting the missions. But because of the sophistication of the Voyager craft, backed by the ingenuity of the engineers and controllers on the ground, the most serious problems have been solved or circumvented. In fact, by working on the problems, the ground support crew acquired a better understanding for the capacities of the Voyager spacecraft. At present, Voyager 1 is headed out of the solar system, while Voyager 2 is on course for Uranus, where it will arrive just less than three years from now.

Up to this point, *Voyages to Saturn* is simply another competent space book with lots of facts and nice pictures. When Morrison describes the actual events of the Saturn encounters, however, the book really takes off. Telling the story from his insider's perspective, Morrison details the excitement and frustrations that marked the encounter days. First came Voyager 1: with each fresh observation, long-established ideas and theories were tossed aside to be replaced by newer theories. Later, with the Voyager 2 encounter, many of these new theories proved unsupportable and were in turn replaced by newer ones. Morrison puts the reader behind the scenes as the scientists latch onto each piece of data and push it as far as possible to extract every last bit of information.

Most observers expected the rings to be the center of attention, and this proved to be the case. As one scientist put it, "In this strange world of Saturn's rings, the bizarre becomes commonplace." There were more rings than anyone could have planned for: the final count is well into the thousands. Theories were formulated, often in vain, to explain the weird and unexpected ring structures like the spokes and the braided F-ring. Voicing frustration at being unable to explain what had been discovered, one scientist was heard to exclaim that the rings ". . . are not just eccentric — they're stark, raving, mad!"

For all its success, the Voyager missions had their share of failures, too. The most notable occurred in the midst of the Voyager 2 encounter. A misfiring thruster, a jammed camera scanning platform — and suddenly what should have been some of the best pictures of Saturn and its rings turned out blank. The cameras were pointing toward the wrong section of the sky. Although engineers and ground crew labored day and night to correct the problem — and largely succeeded — the best opportunity for pictures had passed.

In spite of this and other lesser mishaps, the project scientists deemed the Saturn encounters a 200% success. The quantity and quality of data collected was twice as great as they had expected at the start — enough for scientists to work on for many years.

Unmanned craft are supposed to elicit a "ho-hum" reaction from the general public, yet the Voyager photographs engendered great interest and excitement from many people in all walks of life. In acknowledgement of this, Morrison filled *Voyages to Saturn* with a wide range of excellent pictures. Even better, nearly every photograph is labeled with its identification number so that any reader interested in purchasing a picture can order it from the Space Science Data Center at the Goddard Space Flight Center in Greenbelt, Maryland. This alone is almost worth the price of the book.

*Voyages to Saturn* is not for the casual reader looking for a quick survey of the Voyager encounters with Saturn — it's far too absorbing and detailed for that. Instead, Morrison has written a book for those interested in a thorough introduction to Saturn and the Voyager missions to it. And for anyone who intends to delve deeper, *Voyages to Saturn* is an excellent starting point. *Robert G. Nichols*

### The Accidental Universe
P.C.W. Davies
139 pages, hardcover, $19.95;
paperback, $9.95
Cambridge University Press (1982)

Why is the universe the way it is? Why, for example, is the proton 1836 times more massive than the electron? Why is gravity so weak? In spite of spectacular recent progress in understanding the basic forces of nature, these and other fundamental features of the physical world seem to be arbitrary and meaningless.

Chapter one summarizes most of the physics required to understand the rest of this book, which examines why many physicists now see the cosmos as an "accidental" universe. Mathematics is used frequently, but is largely restricted to elementary algebra. The book is intended for the scientifically-inclined non-specialist; the level of writing corresponds to that found in *Scientific American*.

*The Accidental Universe* is a step-by-step examination of the physical world's arbitrary nature. It culminates in a discussion of the only systematic attempt outside religion to explain the extraordinarily contrived appearance of our universe — the so-called *anthropic principle*. This principle relates basic features of the cosmos to our own existence as observers. Some scientists go so far as to claim that our existence can be used as a "biological selection effect" to explain the otherwise mysterious numerical values of the fundamental physical constants — that is, the universe is the way it is because we had to be in it! Although some find the philosophical basis of the anthropic principle objecitonable, Davies says that "it is difficult not to be struck by some of the surprisingly fortuitous accidents without which our existence would be impossible."

Davies' book is a bit too technical to be considered a popular work. Although he clearly describes the physical arguments, he does so in more detail than most readers would care for. On the other hand, the book would make an ideal supplementary text for an undergraduate astronomy course. *The Accidental Universe* will easily generate useful discussion from students — after all, their very existence may be related to a "fine tuning" of the laws of physics. *Francis Reddy*.

### Physics of Stellar Evolution and Cosmology
Howard S. Goldberg and
Michael D. Scadron
390 pages, hardcover, $59.50
Gordon and Breach (1982)

This is a nice introduction to the physics behind modern astronomy. Goldberg and Scadron have created a textbook for physics students interested in astrophysics, but the text between the equations is written well enough to appeal to interested non-specialists. Although the book is an intermediate-level one-semester text on astrophysics, the authors avoid calculus as much as possible "in order to focus on the physical principles." The book *is* tightly focused, with many useful line drawings that may get a casual reader interested in the mathematics.

In short, this is a fine book for those looking for a detailed presentation of modern astrophysics and the workings of science in general. The big drawback, however, is the price. A useless page of color photos (the Orion, Ring, and Veil

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**Applications of Modern Dynamics to Celestial Mechanics and Astrodynamics**
Victor Szebehely, ed.
373 pages, hardcover, $100
D. Reidel (1982)

Celestial mechanics, or dynamical astronomy, is that which deals with the motion of natural celestial bodies. This volume gathers papers presented at a NATO Advanced Studies Institute conference held in 1981. The papers range from the application of new techniques to the mostly unsolved problems of celestial mechanics, like the stability of the asteroid belt, formation of planetary rings, multiple collisions of celestial bodies, and the long-term stability of the solar system itself.

**The Comparative Study of the Planets**
A. Coradini and M. Fulchignoni, eds.
516 pages, hardcover, $59.50
D. Reidel (1982)

This book is an overview of comparative planetary study compiled from papers delivered at the NATO Advanced Study Institute held in September 1981. Topics discussed include the origin and dynamics of bodies in the solar system, cosmochemistry and the ages of planetary bodies, and the interaction of planetary magnetic fields with the solar wind.

**Progress in Cosmology**
A.W. Wolfendale, ed.
360 pages, hardcover, $54.50
D. Reidel (1982)

Many areas of research have a bearing on the origin and evolution of the cosmos: elementary particle physics, the study of cosmic rays, and astronomy across the entire electromagnetic spectrum. This volume is a collection of papers delivered at the Oxford International Symposium in September 1981.

**The Nature of Symbiotic Stars**
M. Friedjung and R. Viotti, eds.
310 pages, hardcover, $43.50
D. Reidel (1982)

The term "symbiotic stars" was first used in 1941 to describe stars of two essentiallly dissimilar kinds that seem to occur together and seem to "need" one another. Since then, the term has come to signify a strange group of objects that displays a combination of low-temperature absorption features and high-temperature emission lines in their spectra and undergo nova-like outbursts. While most researchers have considered them binary, many have supported single-star models to explain these strange objects. The dividing line between novae and symbiotic stars is muddled, and, as the editors point out, doubts can even be raised that a class of "symbiotic stars" really exists. The book is a collection of research papers delivered at an IAU Colloquium held in August 1981.

**Sun and Planetary System**
W. Fricke and G. Teleki, eds.
538 pages, hardcover, $65
D. Reidel (1982)

Solar system studies have made unprecedented progress in recent years. This collection of papers from the Sixth European Regional Meeting in Astronomy, held in October 1981, presents reports on the Sun as a star, the Earth from astronomical and geophysical viewpoints, the interplanetary medium, planetary physics, comets, and minor planets. A special section is devoted to a problem shared by other branches of astronomy — atmospheric refraction.

**Essays in Nuclear Astrophysics**
C.A. Barnes, D.D. Clayton,
and D.N. Schramm, eds.
562 pages, hardcover, $75
Cambridge University Press (1982)

Cosmologists say that the universe consisted of hydrogen and helium after the Big Bang. How did the present diversity of chemical elements originate? Researchers in nuclear astrophysics have tried to answer this and other questions about the nuclear and chemical evolution of the cosmos. This collection of 23 essays is dedicated to W.A. Fowler, who practicallly began the field, and provides an overview of the current application of nuclear science to astronomy. Aimed at a professional audience, the book discusses the abundances of chemical species on Earth, in meteorites, in stars, and in interstellar space. Supernova dynamics and the relationships between particle physics and cosmology are also discussed.

**Galactic X-Ray Sources**
P.W. Sanford, P. Laskarides, and
J. Salton, eds.
450 pages, hardcover, $45
D. Reidel (1982)

This volume is based on material largely presented at a NATO-sponsored conference and is intended for third-year undergraduates and postgraduates in astronomy.

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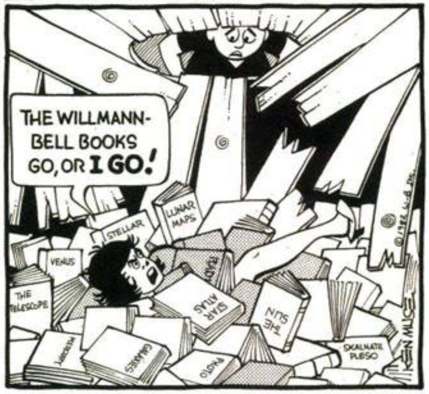

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# eye on the sky

## conjunctions light up the sky

by Fred Schaaf

### the wanderers

Several interesting planetary events take place this month: Saturn grows brighter and displays open rings, Mars and Venus pass close by each other, and Mercury undergoes a near-occultation with a 6th magnitude star. One of the most exciting events will be the first of this year's three Jupiter-Uranus conjunctions; these two planets haven't appeared together in the sky since 1969.

For the first half of February, watch magnitude -1.6 **Jupiter** drift right past the star Psi (ψ) Ophiuchi and toward the vicinity of Omega (ω) Ophiuchi. There Jupiter will slowly overtake **Uranus**. The conjunction will occur on the morning of February 17, when Jupiter is only 46 minutes of arc north of Uranus. The pair will then be 79° west of the Sun in the morning sky. If you have dark skies, you can probably see Uranus with the naked eye — it will shine at about magnitude 5.9.

Besides their close accompaniment by stars in Ophiuchus, Jupiter and Uranus will also enter into a wider conjunction with Alpha (α) Scorpii, **Antares**. On the evening of the 14th, Uranus will lie 4°44′ north of Antares, and on the evening of the 16th, Jupiter will lie 5½° north of Antares. On the evening of the 17th, all three objects will form a nearly straight line running north-south.

If you don't get up to see Jupiter and Uranus floating high over Scorpius before dawn, you can catch their second conjunction on May 16, when the two are near opposition and easily seen in the evening sky. But added incentive for early morning observing sessions this month is the presence of another prominent planet, a favorite for observers of all types.

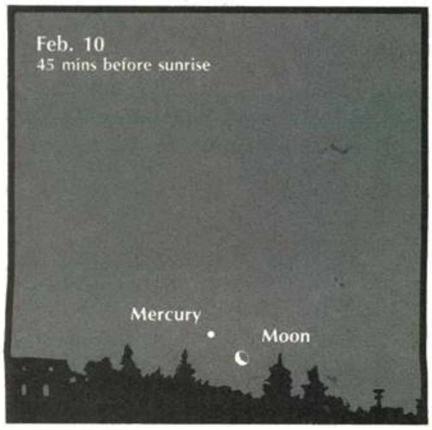
**Saturn** is currently located far west of Jupiter and Uranus. Telescopic observers will be delighted to find Saturn's rings wide open — a full 17° from edgewise — and looking their best in years. Naked-eye viewers will find that the open rings also add to Saturn's brightness, which is predicted to be magnitude 0.6 by month's end. Decreasing distance between us and the planet will cause Saturn to continue to brighten until April, when it reaches opposition.

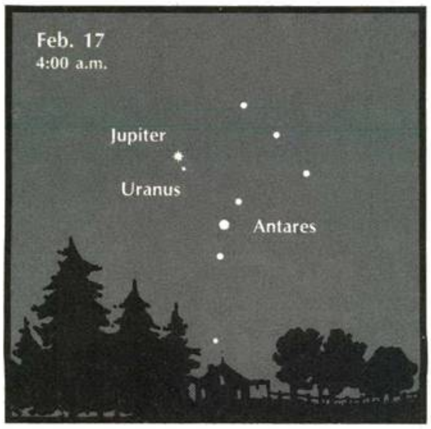
Saturn rises late in the evening this month and can be viewed before midnight, though low in the east. It will flirt with the Virgo-Libra border for a while in February but will then turn back with retrograde motion before crossing the line. The fairly dim star just to the northwest of it is Kappa (κ) Virginis.

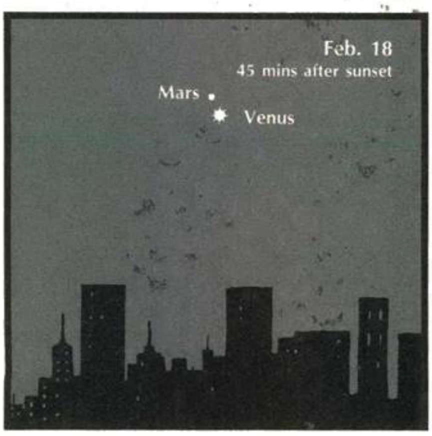
Another attraction in the predawn sky is **Mercury**, which reaches greatest elongation on the 8th. Though 25.7° from the Sun on that date, Mercury will not be a conspicuous object, due to the angle of the ecliptic at this time of year. On the morning of the 26th, when Mercury is still 21° from the Sun, 6th magnitude **31 Capricorni** will be just 41′ south of the planet. But this will be difficult to observe, even if you are equipped with a telescope.

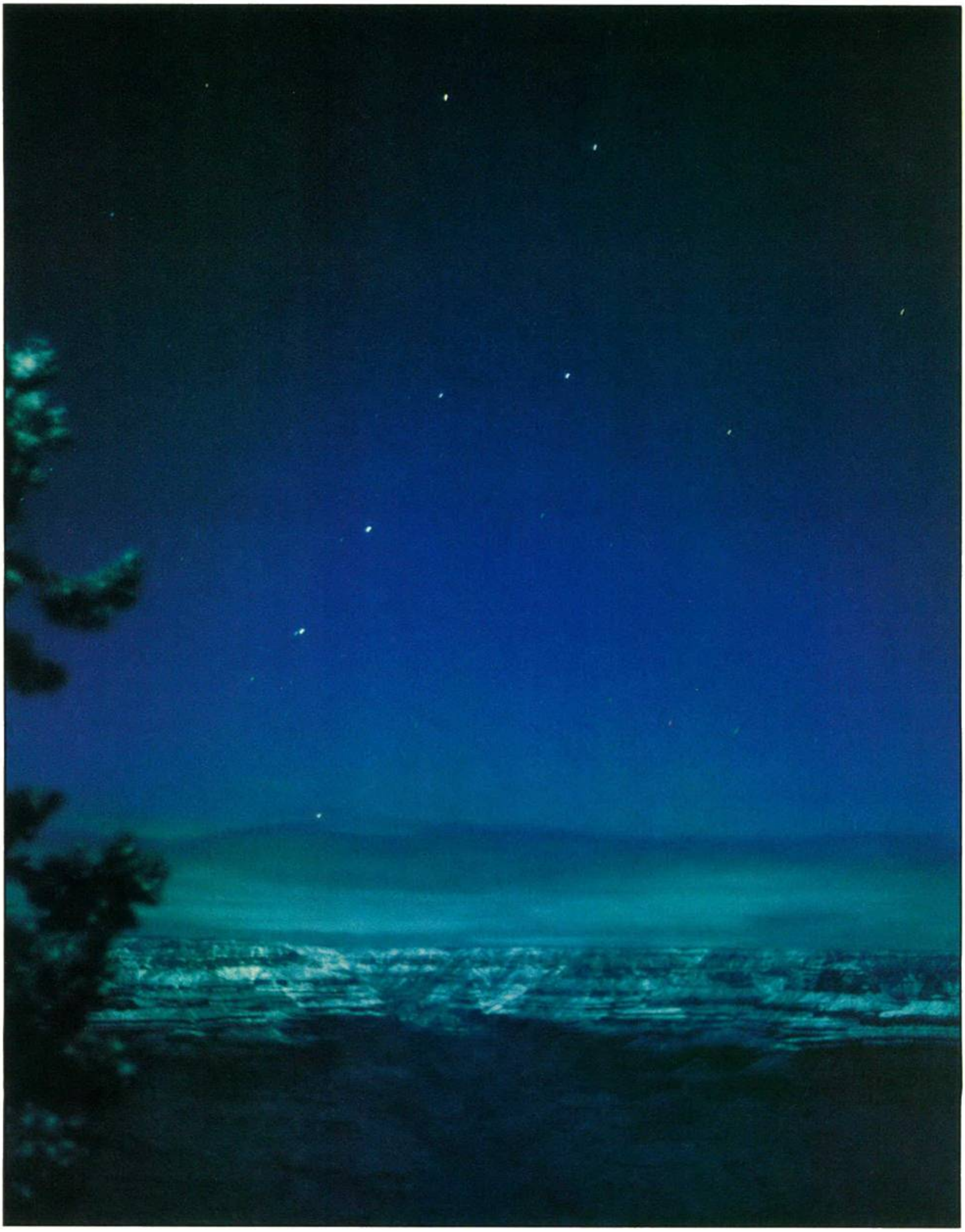
The remaining two naked-eye planets are conveniently located in the after-sunset sky this month. **Mars** and **Venus** undergo the first of their three 1983 conjunctions on the evening of February 18, when U.S. observers can glimpse them at or near their very closest. The 32′ separation between them will be the least of any Venus-Mars conjunction until 1991. The pair will be 26° from the Sun; Venus will shine at magnitude -3.4 and Mars at 1.4.

The fate of the two in the coming months is opposite: Venus will keep brightening and will be high in the spring sky until it reaches greatest elongation from the Sun in June; Mars will fade into the Sun's afterglow and will reach conjunction with the Sun in the same month. In its slow struggle to stay in the evening sky, Mars passes near the vernal equinox around the end of this month — just three weeks ahead of the Sun's passage that signals the beginning of spring.


Feb. 10
45 mins before sunrise

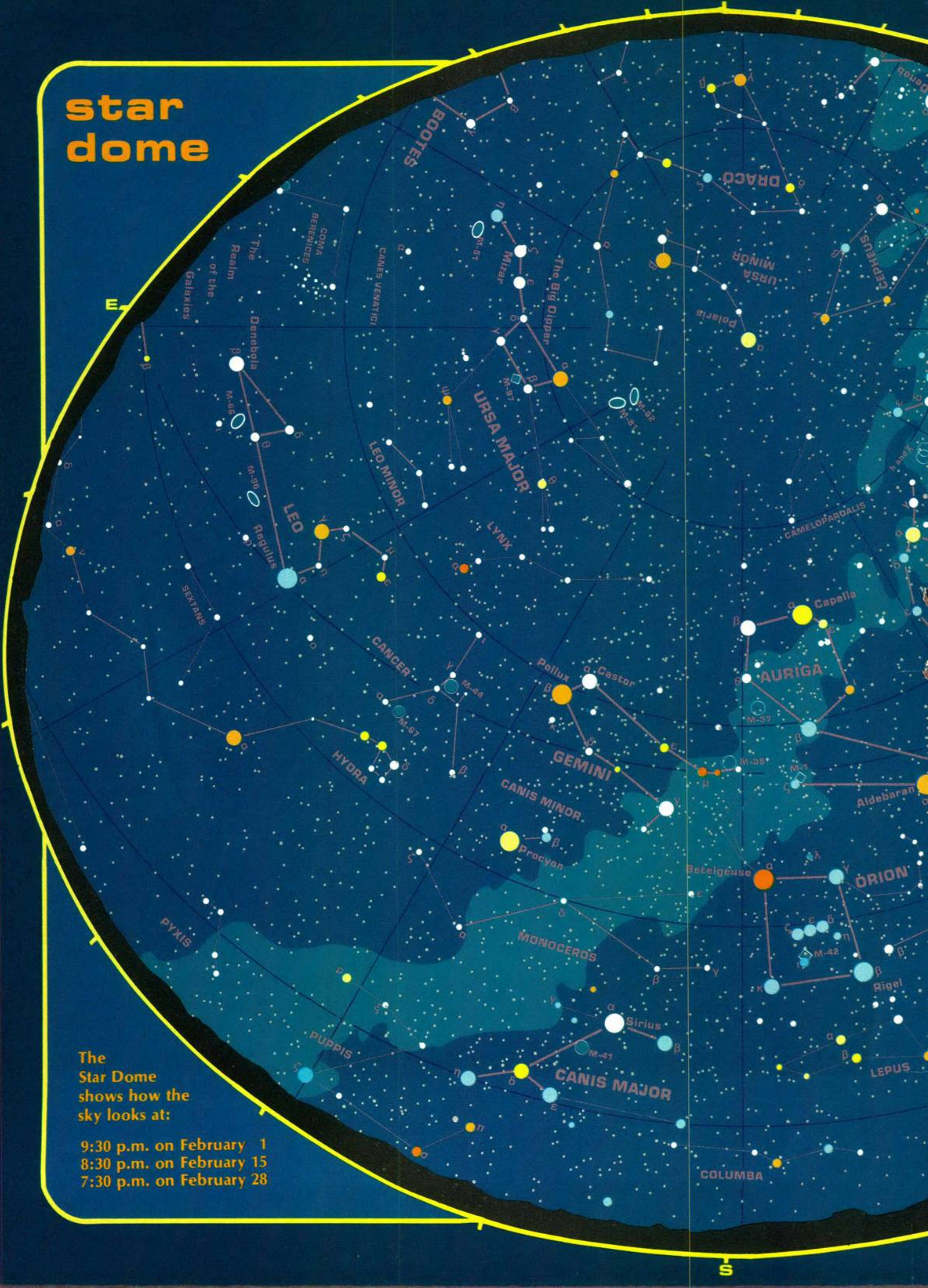

Feb. 17
4:00 a.m.


Feb. 18
45 mins after sunset



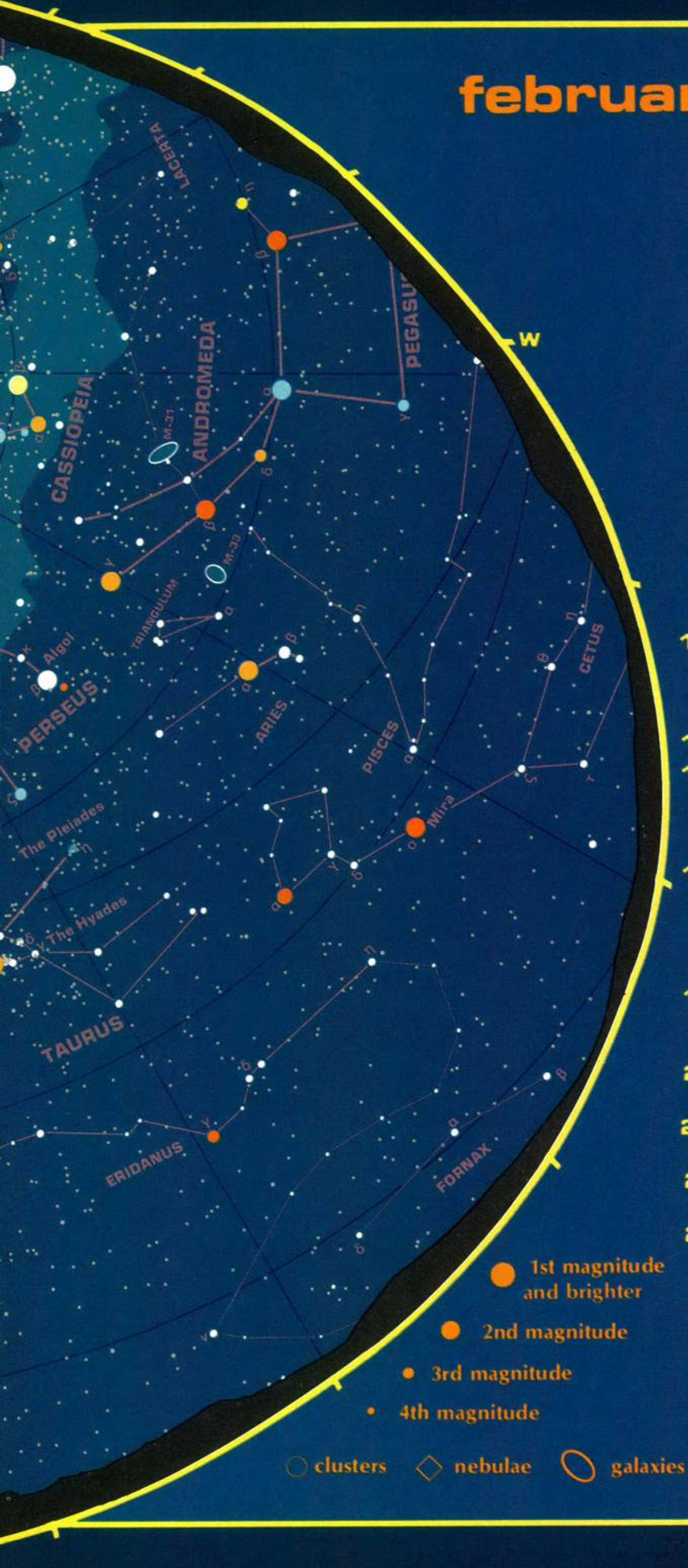
At midnight on January 6, 1982, Vernon E. Grove, Jr. made this spectacular photograph of the Big Dipper rising over the Grand Canyon. During the 18-second exposure — made on Kodachrome 64 film with a 35mm f/1.4 lens — moonlight illuminated detail on the sides and at the bottom of the canyon.

# star dome


BOOTES
DRACO
CEPHEUS
Deneb
URSA MINOR
Polaris
COMA BERENICES
The Realm of the Galaxies
CANES VENATICI
M-51
Mizar
The Big Dipper
Denebola
M-66
M-96
LEO
Regulus
LEO MINOR
URSA MAJOR
M-97
M-82
M-81
LYNX
CAMELOPARDALIS
h and χ
SEXTANS
CANCER
M-44
M-67
HYDRA
Pollux
Castor
GEMINI
CANIS MINOR
Procyon
Capella
AURIGA
M-37
M-35
M-1
Aldebaran
Betelgeuse
ORION
M-42
Rigel
MONOCEROS
PYXIS
PUPPIS
Sirius
M-41
CANIS MAJOR
LEPUS
COLUMBA
E
S

The Star Dome shows how the sky looks at:

9:30 p.m. on February 1
8:30 p.m. on February 15
7:30 p.m. on February 28


LACERTA
PEGASU
W
ANDROMEDA
CASSIOPEIA
M-31
M-33
TRIANGULUM
Algol
PERSEUS
ARIES
PISCES
CETUS
Mira
The Pleiades
The Hyades
TAURUS
ERIDANUS
FORNAX
1st magnitude and brighter
2nd magnitude
3rd magnitude
4th magnitude
clusters
nebulae
galaxies

# february sky almanac

**1st** Between now and about a week from now is your best chance to see Mercury in the morning sky — look low in the southeast.

**3rd** Tonight Saturn will lie 2° south of the Moon.

**4th** Last Quarter Moon is at 2:17 p.m. EST.

**6th** In the morning sky, the Moon will overtake Jupiter, passing 1.5° north of it.

**8th** Mercury is at greatest western elongation from the Sun in the morning sky. You will have about two more weeks to observe it.

**10th** The Moon is at apogee this morning: 252,441 miles. It will pass 2° south of Mercury in the predawn sky.

**12th** New Moon occurs at 7:32 p.m. EST.

**14th** Right after sunset tonight, you can see a crescent Moon preparing to overtake Venus and Mars in the western sky.

**17th** In the early morning hours, you can see Jupiter about 5° north of the bright star Antares in Scorpius — and perhaps spot Uranus just south of Jupiter.

**18th** Look for Mars and Venus close together in the western sky soon after the Sun goes down.

**20th** First Quarter Moon comes at 12:32 p.m. EST.

**22nd** Mercury is at aphelion — farthest from the Sun.

**25th** The Moon is at perigee this evening: 223,818 miles.

**27th** Full Moon occurs at 3:58 a.m. EST.

# the starry sky

Below hunter Orion are his two celestial dogs, **Canis Major** and **Canis Minor**. The two great "dog stars" are Sirius, the brightest star in the sky, and Procyon. Other fine sights in the February heavens include the luminous "river" which separates Sirius and Procyon, and Canopus, another star of extraordinary brilliance — which some Americans can see pretty well, although briefly.

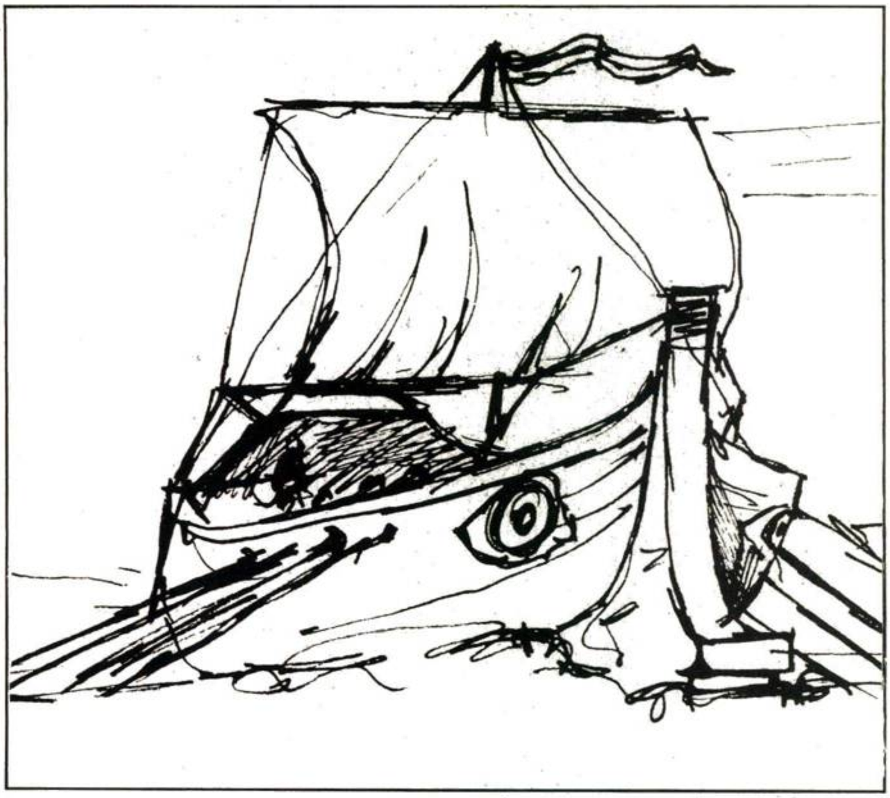
The luminous river is, of course, the Milky Way. After trickling through Perseus and Auriga, the winter Milky Way runs southward, dividing the brightest winter constellations into two groups. It isn't particularly brilliant compared to the summer stretch that runs through Cygnus and Sagittarius, so you can easily judge a night's quality by seeing how much of it is visible.

**Taurus** holds a number of interesting objects. Far ahead of the winter Milky Way glows a pocketful of stars, the **Pleiades**. And high up in the face of the bull are the magnificent **Hyades** cluster and bright **Aldebaran**, whose name means the follower. Indeed, the orange star mimicks the path of the Pleiades cluster as it moves across the sky. The bull's horns are thrust into the starriness of the Milky Way: **Beta Tauri**, also called **El Nath**, reaches to high Auriga, and fainter **Zeta Tauri** lies near the Crab Nebula.

Also just ahead of the central course of the Milky Way is the most striking constellation of all, **Orion**, whose mighty red and blue giants we toured last month. Besides the symmetrical belt of three stars, there are the bright stars of his frame, **Bellatrix** and **Saiph**, and the most brilliant, **Rigel** and **Betelgeuse**. Are your skies good enough for you to trace the outline of Orion's shield, which guards against Taurus' charge? Or Orion's club, northeast from Betelgeuse, from which October's Orionid meteors appear to pour? You should have no trouble identifying his sword, in which shines the amazing **Great Nebula of Orion**. But what about his head? It is marked by three dim stars that form a compact triangle.

Northeast of Orion's club stands **Gemini** the twins. Its most famous stars are **Castor** and **Pollux**, stars that mark the heads of the twins. The feet of the twins are prominent and interesting; the northernmost foot is home for **M-35**, a huge open star cluster that can sometimes be glimpsed with the naked eye, even in suburban skies. Like Orion's club, the feet of Gemini are immersed in the glow of the

**On October 15, the waning Moon and Mercury passed within 4° of each other in the early morning sky. From Arlington, Virginia, L.H. Price set his camera and 135mm f/4 lens on a sturdy tripod and exposed for 5 seconds on Kodachrome 64. This month there are *seven* Moon-planet conjunctions.**



winter Milky Way, which gets brightest in the constellations **Monoceros** the unicorn and **Puppis**, the poop deck of the old ship Argo. Near the feet of Gemini, due east of Betelgeuse, is a diagonal line of faint stars which we can imagine to be the unicorn's horn. Near this line you can detect the soft glow of a star cluster — **NGC-2244**, around which lies the famous **Rosette Nebula**. Several other impressive clusters lie in the region.

February is the month when **Sirius**, the brightest star in the sky, is best visible. Sirius is so bright that in theory it can cast shadows. No star has ever shone regularly as bright as Sirius; a smattering of supernovae may have outshone it, and Nova Aquilae 1918, the brightest known nova, peaked at just under Sirius' brightness. It is a close double star (see The Backyard Astronomer, page 84, for more about Sirius) whose companion is a white dwarf. So when you go out to gaze at this star, you have a lot to reflect upon. It is only 8.7 light-years away, and contains much more mass than the Sun. It also outshines the Sun by a comfortable margin. Yet its Earth-sized companion glows dimly, as a reminder of what happens at the end of a star's life.

Observers disagree over Sirius' color. Robert Burnham, Jr., in *Burnham's Celestial Handbook*, states that "the star is a brilliant white with a definite tinge of blue." Other observers see it as pure white. Go out on a steady night and see what you think.

Although Sirius has no equal, this month some low-latitude observers can get a look at its closest rival, **Canopus**. Since it is located at about -53° declination, it's possible to glimpse Canopus as far north as 37° north latitude, which includes Norfolk, Tulsa, and Fresno. If you search for the star, remember that it lies not far from due south of Sirius, and almost exactly due south of Beta Canis Majoris (Murzim).

## skylore

According to R.H. Allen, early German astronomy books called Canopus the *Schiffstern*, or "ship-star." Canopus might also be termed the "spaceship-star," since a number of spacecraft have used it as a guidestar.

Canopus has long been famous due to its brilliance. "Kanobos," as Eratosthenes of Alexandria termed it, has one of the oldest star names still in use. As legend has it, the star was named for Canopus, a chief pilot in the fleet of Menelaus, the husband of Helen of Troy. According to this story, the fleet of Menelaus was blown off course on its way home from the Trojan War, around 1250 B.C. Canopus safely brought the ships to land near a mouth of the Nile River, but when he set foot on shore a snake bit him and he died.

The grateful King Menelaus honored him by changing the name of the city of Karob to Canopus. There he raised a monument to his pilot. More than a millennium later, an astronomer named Ptolemy made observations from the terraced walls of the temple of Serapis in this city. By this time the city had become somewhat of a resort of vice and dissipation for the residents of nearby Alexandria. Almost 1500 years later, the ruined village of Canopus — built over by the villagers of Al Bekur — was the scene of Lord Nelson's historic Battle of the Nile and Napoleon's victory over the Turks a year later.

So the site named after Menelaus's pilot went on to have a fascinating and varied history. But from our point of view, an even greater honor was also bestowed on the pilot — Menelaus gave his name to a brilliant star, which in those days rose only about 7½° above the horizon at the city's latitude.

Another theory derives the name Canopus from Kahi Nub, Coptic for "golden earth." An Egyptian priest-poet as far back as about 1500 B.C. called the star Karbana.

Nearly 3,000 years later the poet Dante wrote of *Tre Facelle*, which R.H. Allen reports were not only the three theological virtues — Faith, Hope, and Love — but also the stars Canopus, Achernar and Fomalhaut. Dante's work doesn't seem to support this, however.

Canopus has always been highly revered in the great deserts of the south. According to Allen, who was usually careful in his assertions, several major structures at Karnak built in 2100 B.C. and 1700 B.C. marked the star's setting. In Arabia and Persia, Canopus gave rise to many proverbs and was believed to give gems their color and keep people from disease.

Allen writes that the Chinese worshipped Canopus as late as 100 B.C. They called it Laou Jin, the "Old Man"; but other sources link Canopus (or perhaps Spica) to the god Shou-hsing, who later seems to have been associated with Libra. Shou-hsing is the god of long life, one of the gods of happiness. He is pictured with white beard and eyebrows and with an immensely high bald head which comes to a point. In statues, he often holds an old staff and the peach of immortality; he is accompanied by a stork or turtle, symbols of longevity.

According to some accounts, this god determines the length of mortals' lives and cannot change the number of years once he has written it down. But one legend tells of a youth who found out he was to die at age 19 and appealed to Shou-hsing. The kindly god could not write different numerals but changed the order of those he had already written, so that the young man lived a happy, prosperous life of 91 years.

Canopus lies within the constellation Carina the keel, which once was merely a part of an enormous constellation, the ship Argo. Canopus was, of course the brightest star in all of Argo — except in April 1843. In that month the marvelous Eta Carinae soared to magnitude –0.8, or just brighter than Canopus, which shone at magnitude –0.72. Eta Carinae is now too faint to see with the naked eye, but there is no telling when it might return to something like its former, Canopus-surpassing glory.

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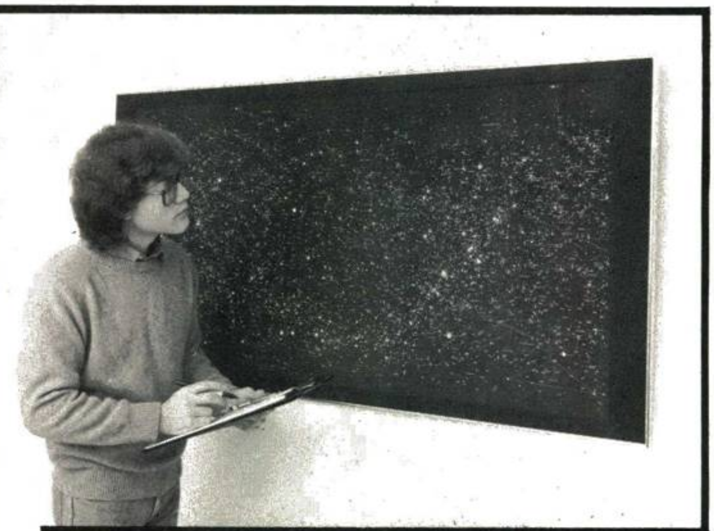

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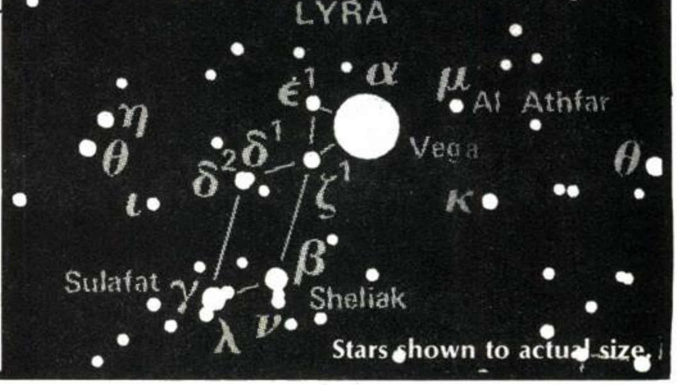

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# backyard photoelectric photometry

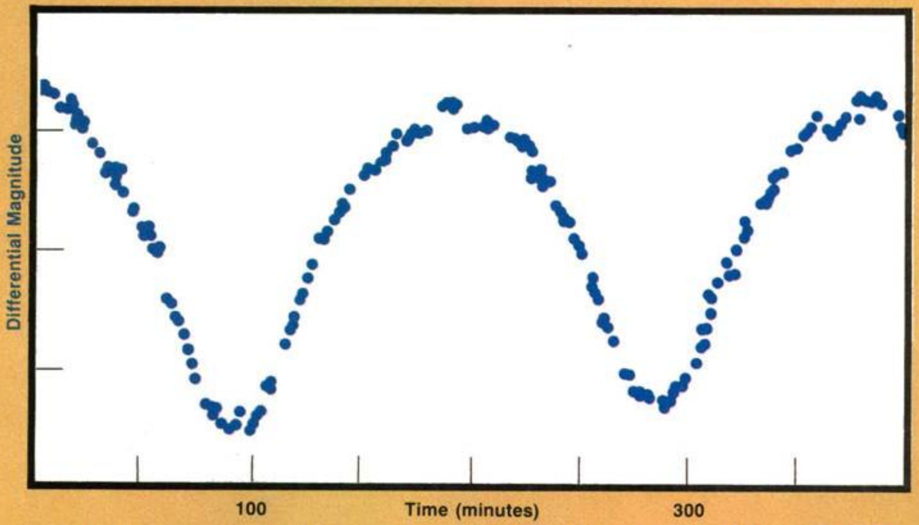
### by Russell M. Genet

Maybe you've heard some things that you just don't believe. Like amateurs doing photometry. Hmph! Is it really possible to routinely measure the brightness of stars to an accuracy of one-hundredth of a magnitude from a small backyard observatory? Seems crazy! And what sort of telescopes and photometers are being used by these backyard astronomers? I bet they cost a million dollars! And anyway, how could it be that amateur astronomers use a technique that was once the exclusive province of professionals?

Well, the answers are 1) yes — one-hundredth-magnitude accuracy is quite possible using differential photometry, which is just about the simplest kind; 2) practically any telescope with a good drive can be used for photometry, and photometers are now commercially available for well under $1000; and 3) the technology has matured in the last few years. What used to be difficult is now relatively easy.

Actually, the first stellar photoelectric measurements were made in 1892 on an amateur's 24-inch telescope. A professional astronomer, G.M. Minchin, and two amateur astronomer friends, G.F. Fitzgerald and W.E. Wilson, made the observations at Wilson's country estate in Ireland. However, after this initial amateur participation, the professionals had the field of stellar photoelectric photometry entirely to themselves for the next 60 years. It wasn't until after World War II that photoelectric equipment became simple enough to be practical even on small observatory telescopes (see ASTRONOMY Forum, this issue).

In the early 1950s, professional astronomer Gerald Kron helped amateur John Ruiz get started in photometry. Soon several other amateurs began making backyard photoelectric measurements of variable stars with telescopes and photometers they'd built themselves. They "reduced" their data by hand calculation — a tedious process, to say the least. Understandably, not many people became interested in photometry.



**Photometry produces light curves — in this case, the light curve of Iota Bootis. The comparison star was nearby Kappa Bootis, and the magnitude scale at left is the difference between the brightness of Iota and Kappa. Each point is the average of seven ten-second measurements, and is accurate to better than a hundredth of a magnitude.**

Recently, however, the availability of convenient commercial Schmidt-Cassegrain and Newtonian telescopes, low-priced and reliable commercial photometers, and the microcomputer revolution have changed all this. Photoelectric photometry has become the fastest-growing area in amateur astronomy.

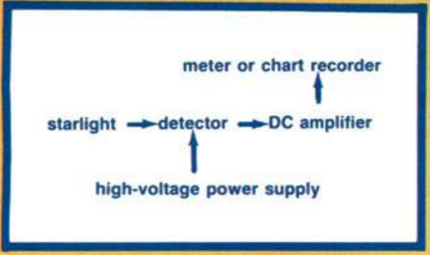
This is fortunate. Professional astronomers need help if they — and we — are ever going to understand some types of stars. Professional telescopes are big, but they're busy with quasars and other exotic objects. When telescope time becomes available, it's usually for a short run of a few nights or a week — hardly a schedule suitable for observing a spotted variable star every clear night for five years.

Here's where the amateur astronomer comes in. From a backyard observatory, a hobbyist can observe whatever he or she wants. One of the first professional astronomers to foresee the true potential of backyard astronomers was Douglas Hall. He realized that dedicated observers who own their own equipment could provide the kind of observations that variable star research needs.

Maybe that sounds intriguing to you. What sort of telescope would you need? Of the amateur telescopes being used today, apertures vary from 6 inches to 30 inches, but 8 inches is the most common. Reflectors, refractors, Cassegrains, and Schmidt-Cassegrains are in use for photometry. The toughest requirement is that *whatever* the size or type of telescope, you'll need a sturdy equatorial mount and an *accurate* clock drive for it. For photometry, a star must be centered in a pinhole and kept centered accurately while its light falls on a detector and the photoelectric measurement is made.

Let's get down to brass tacks: What is this device called a photometer? How does it hook to my telescope? What's it got inside? First, a photometer is simply a gadget that measures light. Basically it's just a box that attaches to your telescope

**Photometer Electronics**



where the eyepiece normally goes. What's inside? Well . . . a photometer is not a very complicated device, but it is tricky to explain. We'll give it a try anyhow. Light from a star enters the box. There it passes through a tiny hole — so only light from the star and a small bit of sky around it go any farther. It next passes through a color filter, so that only a well-defined part of the spectrum registers. Next it goes through a small lens that focuses it on the light-sensitive surface of a photomultiplier tube. It is here that the light gets "detected," or converted into electrical signals. Photons of light knock electrons free to become a current of electrons. An amplifier section inside the tube "multiplies" the current roughly 1,000,000 times; then it's fed into wires and amplified again another 1,000 times by an IC chip — to provide enough current to deflect the needle of a sensitive meter. You now read the meter — and there's your first data point!

If you could follow that, let's look at the process in a little more detail. The hole, or *diaphragm* as photometrists call it, is placed in the telescope's focal plane. Its function is to exclude the light from all the stars except the one being measured. Many photometers have a "flip mirror" in front of the diaphragm so you can view the field of stars and verify that you are looking at the right one.

Then, to check that the star is properly centered before a measurement is made, there's another mirror in the optical path *behind* the diaphragm. It diverts the light to a viewer focused on the back side of the diaphragm. Once you have the right star, you flip out the first mirror and flip in the second mirror to make sure the star is precisely centered. Then you flip the second mirror out of the way and the light proceeds on toward the detector.

The filter allows light of one color through, while blocking light of other colors. Filters allow you to compare "apples with apples" and "oranges with oranges" in the starlight by restricting the measurement to a defined set of wavelengths. The most popular type of photoelectric photometry uses three different filters. One isolates ultraviolet light (U), another isolates blue light (B), and the third isolates the yellow, or visual (V), portion of the spectrum. Not surprisingly, this is called the *UBV System*.

The three filters are usually held in a wheel or slide so they can easily be changed. By measuring the blue, or B, brightness of a star relative to the visual, or V, brightness, you can make a good estimate of a star's spectral type. UBV works pretty well for blue, whitish, and yellow stars, but what about really red stars such as the long-period Mira variables? Since their greatest brightness comes in the red (R) or near-infrared (I), two more filters called R and I have been added to UBV for an extended *UBVRI System*.

After passing through the filter and a little lens to bring it back to focus, light falls on the photodetector. This device converts photons of starlight into an electrical signal. For some years, photometry has been done with photomultiplier tubes. The favorite tube for backyard astronomers is the venerable 1P21 tube, which costs about $85. Photomultipliers are not *easy* to use — which is why photometry was restricted to professional astronomers for so long. You must supply the tube with about 1000 volts DC with an accuracy of a few tenths of a volt, and you must have an electronic circuit that can amplify and measure currents well under one-billionth of an ampere. Luckily, with modern electronics, these requirements are not *too* hard to meet.

Furthermore, solid-state photodiodes are making inroads in photometry. A photodiode is a tiny chip that comes mounted in a tiny metal housing with a clear window for light to enter. They are rugged and can't be hurt by bright light — while photomultipliers can be ruined by bright roomlight. They need only low voltages, and are generally straightforward devices to use. But — and this is a big "but" — they aren't quite as sensitive as photomultipliers.

In general, a photomultiplier has the advantage if you need the greatest possible sensitivity to blue and ultraviolet light. However, unless they are cooled to far below freezing, photomultipliers don't do well in the red and near-infrared. Photodiodes, on the other hand, while weak in the ultraviolet, are strong performers in the red and near-infrared.

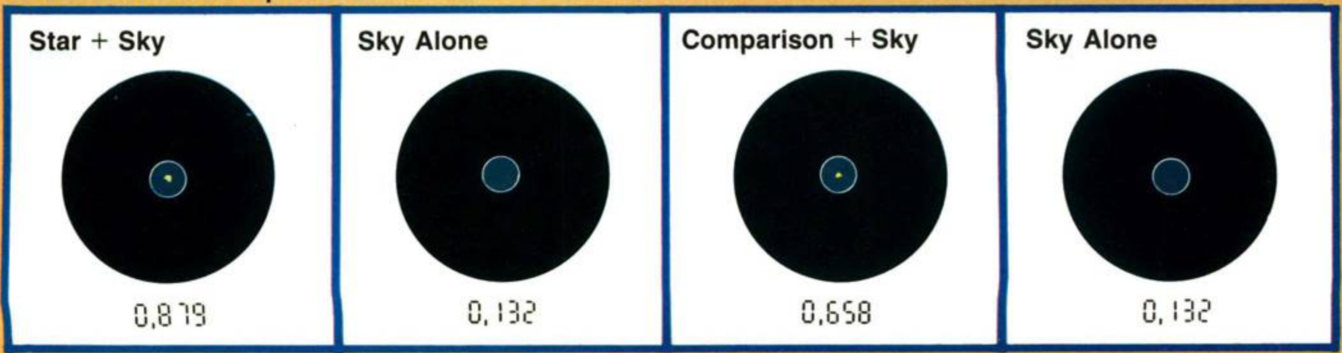
A good example of a low-cost commercial photometer employing a photomultiplier is the Starlight-II made by EMI Gencom, and a good example of a photodiode photometer is the SSP-3 made by Optec. Any of these units costs less than an 8-inch Schmidt-Cassegrain telescope, and all units will fit on one. Those with curiosity, mechanical inclination, or more mechanical inclination than money, can buy the HPO photometer kit. Those with the urge can build a photometer from scratch. My own first "plywood wonder" photometer, featured in TELESCOPE MAKING #5, was used to gather data on the spotted star RS Canum Venaticorum (see "Starspots" in this issue).

At first it might seem that photometry is very simple — you just center a star in the diaphragm and read the light intensity from the meter. By simply doing this for a variable star night after night, you'll eventually get a plot of intensity versus time — a *light curve* — for the star. But this approach is not very accurate because there are other factors causing the light to vary besides the changes in the variable.

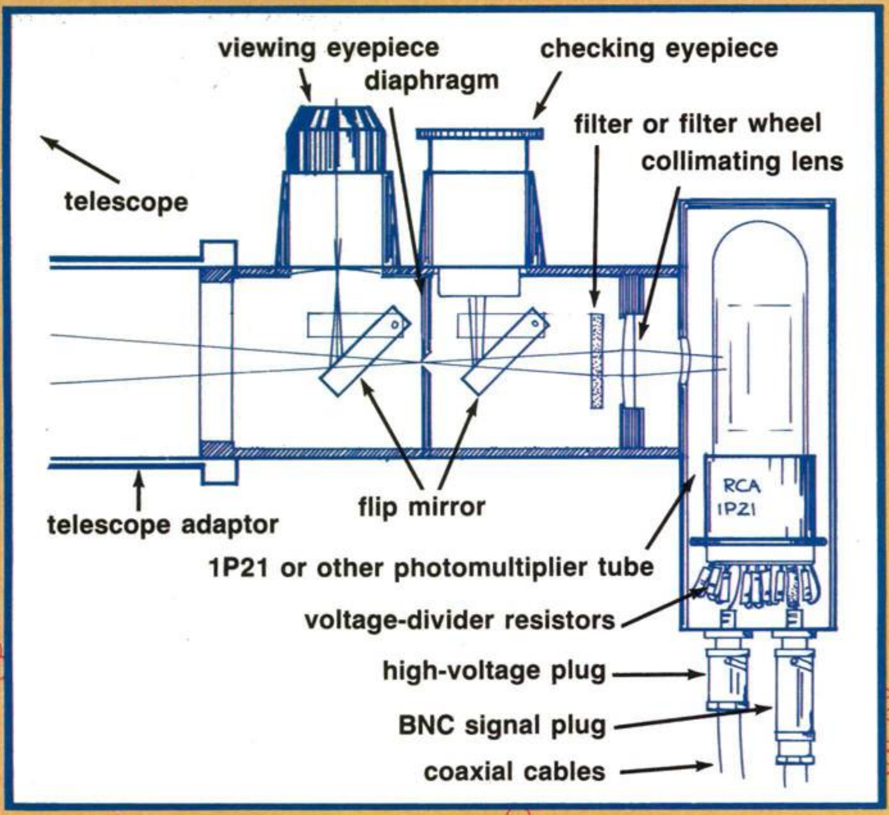
First, if you make your observations at different times of the night, the star will be in different positions in the sky — sometimes high and sometimes low. Near the zenith, the starlight has traveled through the least air and is thus not attenuated as much as starlight from a star close to the horizon. Second, on some nights all the stars are obviously brighter than they are on other, hazier nights. Finally, even with the diaphragm in the photometer, some light from the sky must be included with the starlight in order to get it all. On a night when the Full Moon is up, for example, this sky background light makes the readings higher.

Sound hopeless? Well, it makes the life of a photometrist more complicated, but there are ways of getting around these

**Four Measurements per Datum**



## Inside a Typical Photometer



### Books on Photometry

**Astronomical Photometry**

Arne A. Henden and Ronald H. Kaitchuck, published by Van Nostrand. Explains the UBV system, the Stromgren four-color system, spectral classification, magnitudes and colors, constructing a photometer head, observing techniques, and applications of photometry. Text written at college level.

**Photoelectric Photometry**

Douglas S. Hall and Russell M. Genet, published by the IAPPP. A practical guide for the smaller observatory; chapters on history, observatories and telescopes, photometer heads, electronics, automation, observing techniques, data reduction, accuracy, and choosing an observing program. Written by members of the IAPPP.

**Software for Photoelectric Photometry**

Silvano Ghedini, published by Willmann-Bell, Inc. A comprehensive suite of HP BASIC programs: date and time, air-mass, extinction, second-order extinction, also data reduction programs covering epoch of minimum light, contact times, and determination of the orbital elements of eclipsing binaries. Requires programming experience.

problems. Photometrists resort to several clever tricks.

*Trick No. 1:* Besides measuring the brightness of the variable star along with its unavoidable background, they also measure the brightness of the sky near the star. Then they subtract the reading for the sky from the reading for the sky and the star, thus:

(star plus sky) − (sky alone) = star alone.

Whether the sky is dark or bright no longer matters — in the end it simply gets subtracted off and does not affect the final answer. No wonder photometry is possible even with a bright Moon in the sky or within city limits!

*Trick No. 2:* Besides measuring the variable star and the sky near it, photometrists also measure a nearby star that does not vary and the sky near it. If the stars are close together in the sky, the effects from haze and light absorbed by the air will be the same. If the stars are both low in the sky, they will be dimmer by the same amount. When it is a hazy night, the light from both stars will be attenuated equally.

What this means is that while the light from the two stars changes with distance from the zenith or with haziness, the magnitude difference between the two stars should *not* change. If the variable star changes, and the other star — the comparison star — does not change, then you'll know the extent the variable star actually became brighter or dimmer. The difference between the variable and nearby non-variable comparison star is known as the *differential magnitude* — and that's what you plot when you plot the light curve of the star.

To make a single observation of a variable star — one data point — you must therefore make a minimum of four measurements and afterward perform a series of simple math operations. Here's where home computers (even pocket calculators) come in — they do the tedious math part for you. You have to write a program and make sure it's fully debugged; then you simply key in the readings and let the computer do the tiresome additions, subtractions, multiplications, and logarithms for you.

Let's just take a look at how tough the math is. We'll start with a little piece of your observing log, a record of the numbers you read off a clock and the meter:

| Time | V+Sky | Sky | C+Sky | Sky |
|---|---|---|---|---|
| 11:33 | 0.879 | 0.132 | 0.658 | 0.132 |
| 11:36 | 0.882 | 0.129 | 0.667 | 0.148 |
| 11:39 | 0.863 | 0.131 | 0.632 | 0.129 |
| 11:42 | 0.868 | 0.138 | 0.643 | 0.136 |

In order to obtain a better reading, you took four sets of readings of each star and the sky near it. What next? Average the readings:

11:37.5 0.8730 0.1325 0.6500 0.1363

Next, you find the stars' brightnesses by subtracting the (Sky) reading from the (Star plus Sky) reading.

0.7405 0.5138

Now you must calculate the differential magnitude between the stars. The equation for this looks terrible, but is not difficult to do:

$$\text{Diff. Mag.} = 2.5 \log (B_c / B_V)$$

Your calculator can do this in less than a second. The result is:

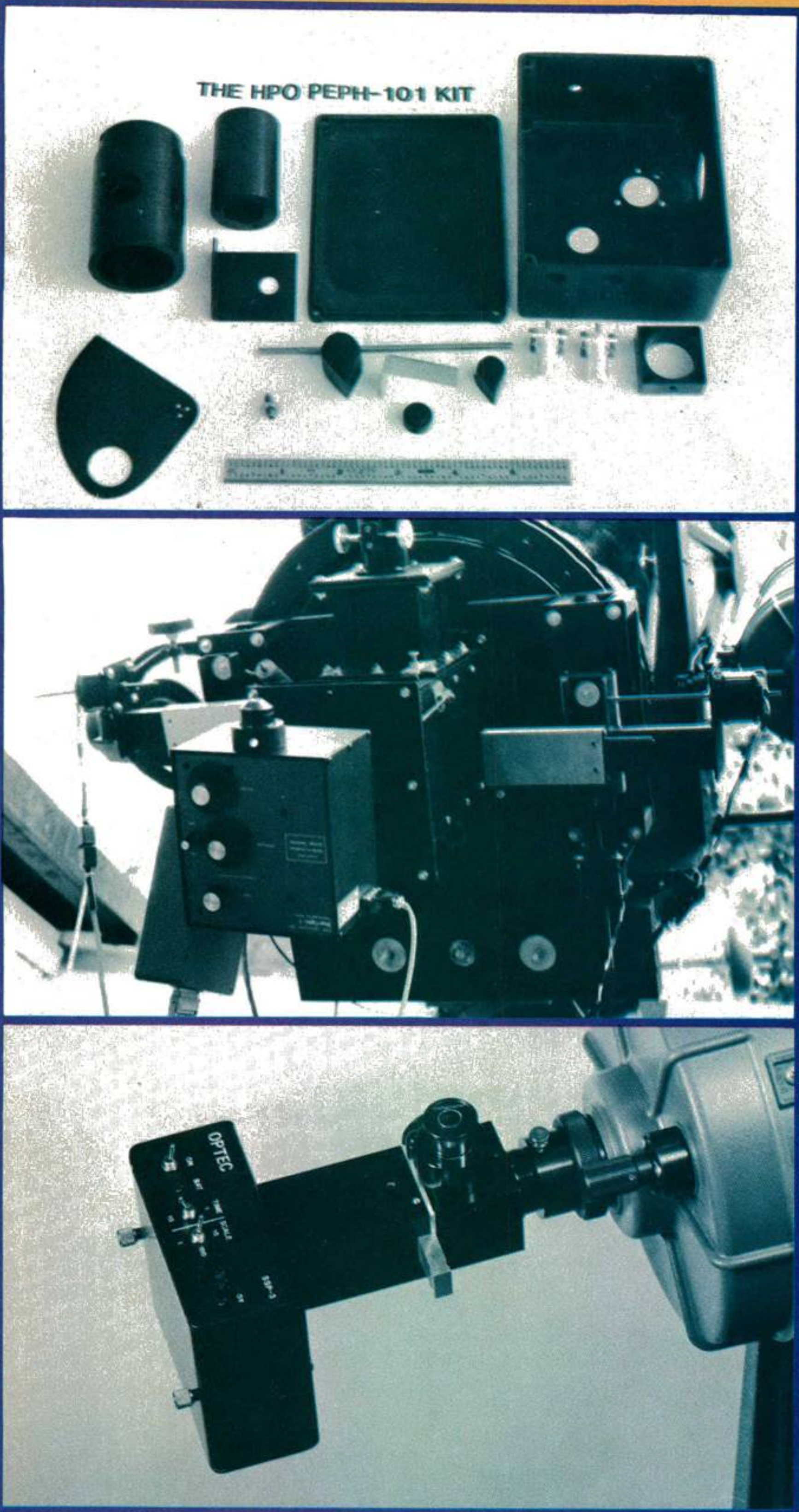
Diff. Mag. = −0.40 magnitudes at 11:37.5.

The number comes out negative in this case because the variable is brighter than the comparison star, and brighter stars have smaller magnitudes.

How often you'd observe this particular star depends on how quickly it happens to vary. If the variations are slow, you might observe it (and lots of other stars, too) about once a week. If it's an eclipsing binary star, it might go down a full magnitude and back up again in three or four hours — so you'd be making measurements of just that star that night.

"What happens next?" you're probably asking. "What do I do with this datum?" First, you can join a group such as the IAPPP or AAVSO, organizations where professional and amateur astronomers work together to define projects and observations that need to be made. Once you get proficient, you simply mail your measurements into the central office. Of course, you can pursue your own observing projects as much as you like or concentrate on supplying data.

If you want to get fancier, and you happen to live in a place where the sky is often clear and crisp, you can go on to



**If you don't want to build a photometer, several are now available. Top: the low-cost, but nicely machined and anodized HPO photometer kit is made by the Hopkins-Phoenix Observatory. The completed instrument is small enough to go on the back of, and easily clear the fork of, a C-8. Middle: the EMI Gencom Starlight-1 photometer on the 16-inch Cass at the Fairborn Observatory. The author built this telescope himself, including grinding the primary. He also helped to design the Starlight-1 photometer. Bottom: the Optec SSP-3 solid-state photometer. It is low in cost, is particularly sensitive in the red and near infrared part of the spectrum, small in size, and operates on a rechargable 9-volt battery. The digital read-out meter is built directly into the back of the photometer.**

### Suppliers of Photoelectric Equipment

- EMI-Gencom, Inc., 80 Express St., Plainview, NJ 11803.
- Hopkins-Phoenix Observatory, 7812 W. Clayton Dr., Phoenix, AZ 85033.
- Nielsen-Kellerman Co., 1066 High Vista Trail, Webster, NY 14580.
- Optec, Inc., 199 Smith, Lowell, MI 49331.
- RCA Electro-Optics and Devices, Lancaster, PA 17604.

"standardize" the filters in your photometer to correct for minor differences between your filters and photomultiplier and the standard UBV or UBVRI System filters and photomultiplier. You do this by observing a set of standard stars and then mathematically converting your photometer's brightnesses into standard magnitudes. You can also go to a lot more trouble to monitor the exact way in which the atmosphere alters the starlight — and again, you can compensate for these differences more rigorously. But these are techniques for later, after you've earned your observer's stripes and feel like taking on bigger challenges.

These fine points need not concern you now — but if your curiosity has been insatiably aroused, they are covered in *Photoelectric Photometry of Variable Stars* and *Astronomical Photometry*. For those with a microcomputer, *Software for Photoelectric Photometry* is invaluable (see the book box for more information).

Do you want to know more? For information on the AAVSO photoelectric program, contact Janet Mattei, 187 Concord Ave., Cambridge, MA 02138. The American Association of Variable Star Observers (AAVSO) counts among its membership the first amateur photometrists such as Louis Boss, John Ruiz, Art Stokes, and Howard Landis. The AAVSO also sponsors an extensive network of observers who make estimates of variable-star brightnesses by eye rather than with a photometer. If you're equipment-shy, you can still get started with no more equipment than a pair of binoculars or a telescope.

The International Amateur-Professional Photoelectric Photometry (IAPPP) now numbers some 400 photometrists from 32 countries. Membership is nearly evenly split between amateur astronomers and professional astronomers. Its members receive a quarterly journal devoted entirely to astronomical photometry — the only journal of its kind in the world. The IAPPP also sponsors a half-dozen symposiums each year; they are usually announced in AstroNews Calendar. For more information on the IAPPP, write Robert Reisenweber, 3621 Ridge Parkway, Erie, PA 16510.

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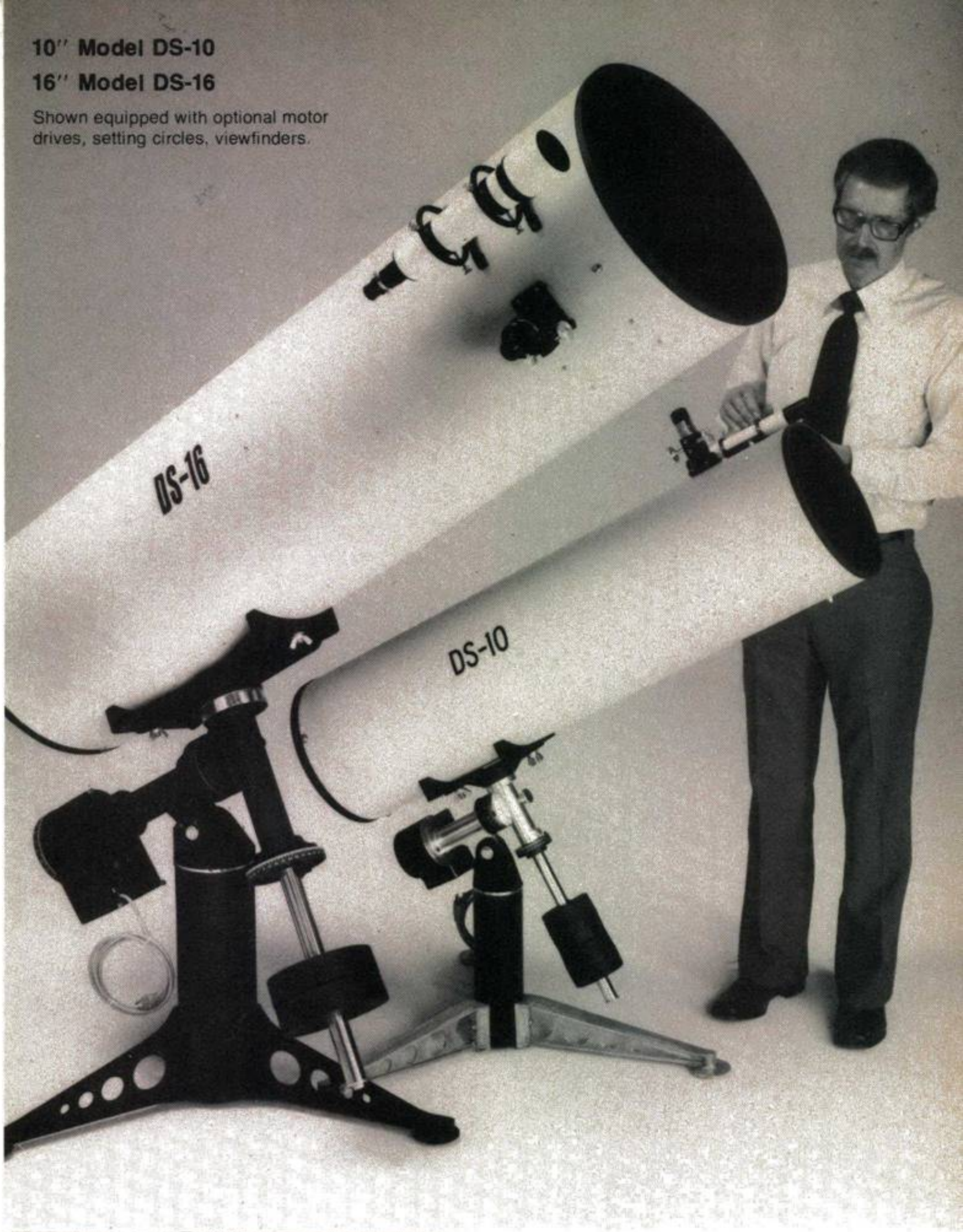

**10″ Model DS-10**
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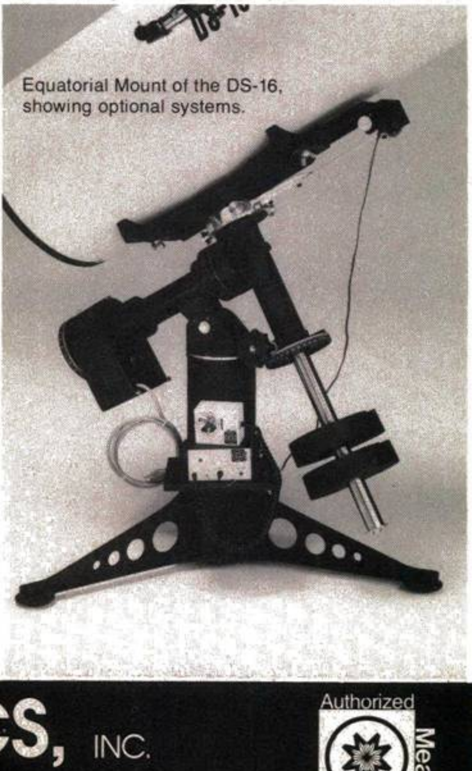
Equatorial Mount of the DS-16, showing optional systems.

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|---|---|---|
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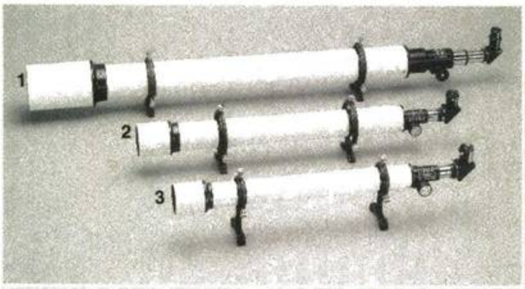

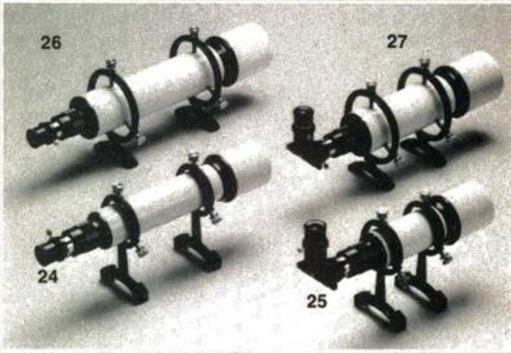

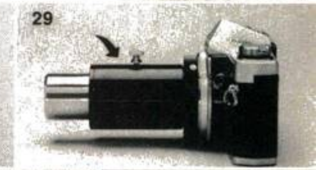

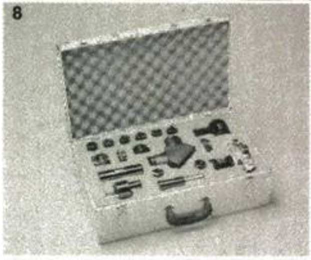

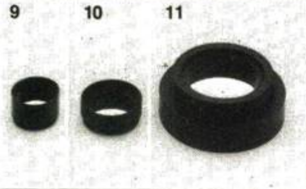

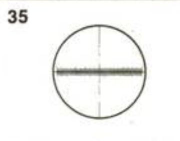

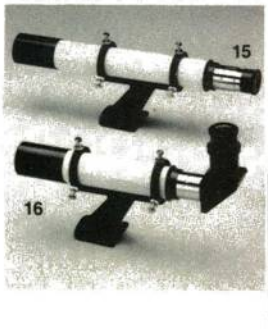

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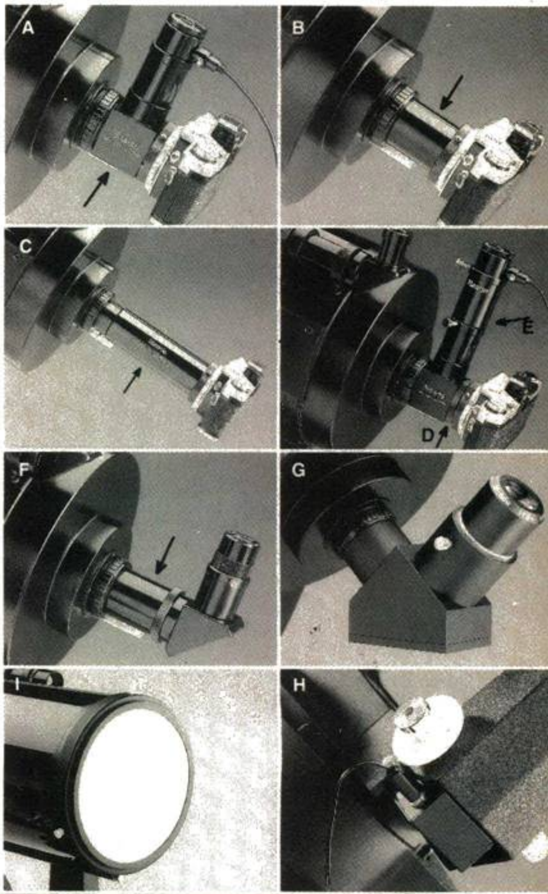

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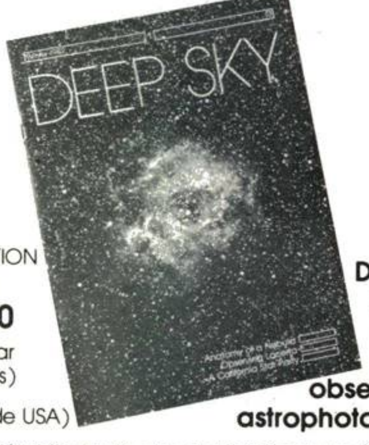

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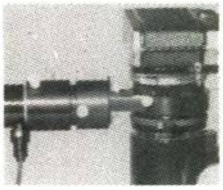

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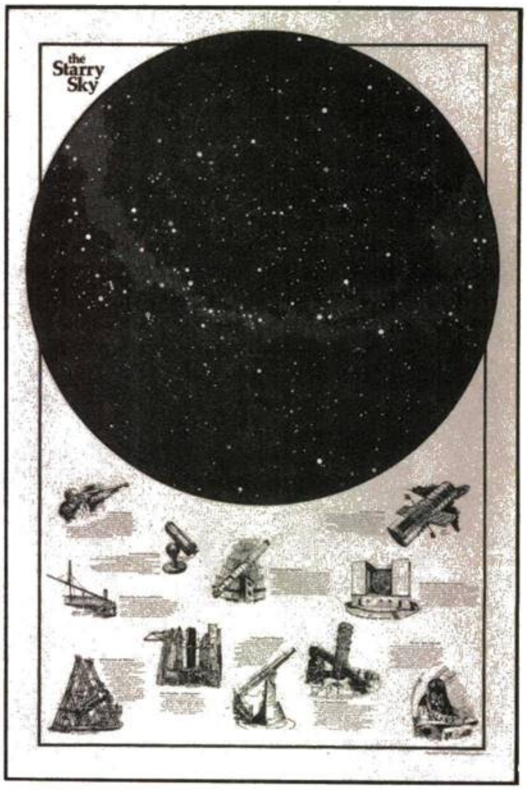

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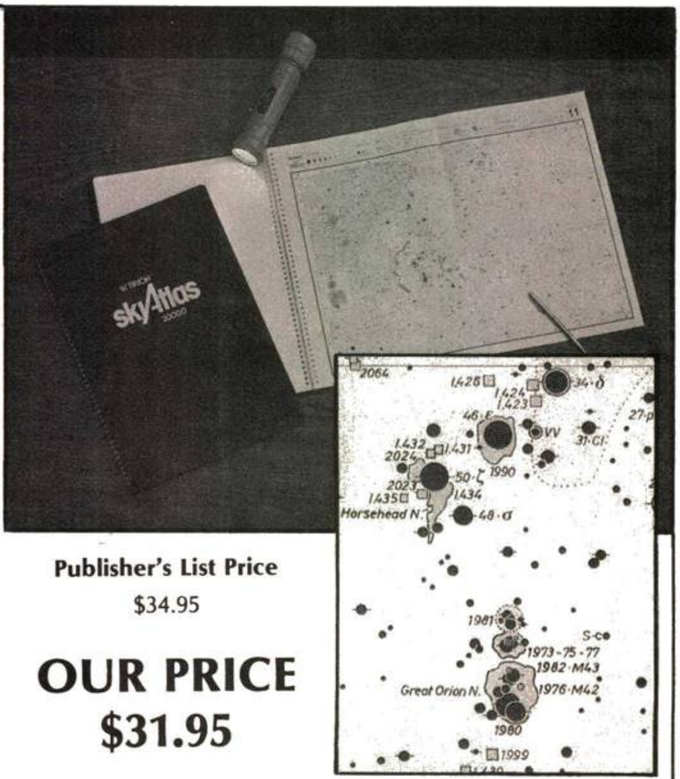

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# ASTRO NEWS

## Voyager 2: Go for Uranus

After 5 years in deep space, NASA's Voyager 2 spacecraft is in relatively good condition for its encounter with the planet Uranus, scheduled for January 24, 1986. Most of the scientific instruments aboard are functioning well after more than 40,000 hours of operating time.

Of the original 104 kilograms of propellant, 67 remain for attitude control and trajectory correction. The two radioisotope generators are furnishing 422 watts of electrical power — 92 watts more than the minimum required. The two main areas of concern over spacecraft health are a scan platform motor that is showing signs of wear and the radio receiver, which can no longer track incoming signals very well. But project engineers at the Jet Propulsion Laboratory are confident that neither of these problems will seriously affect the encounter with Uranus.

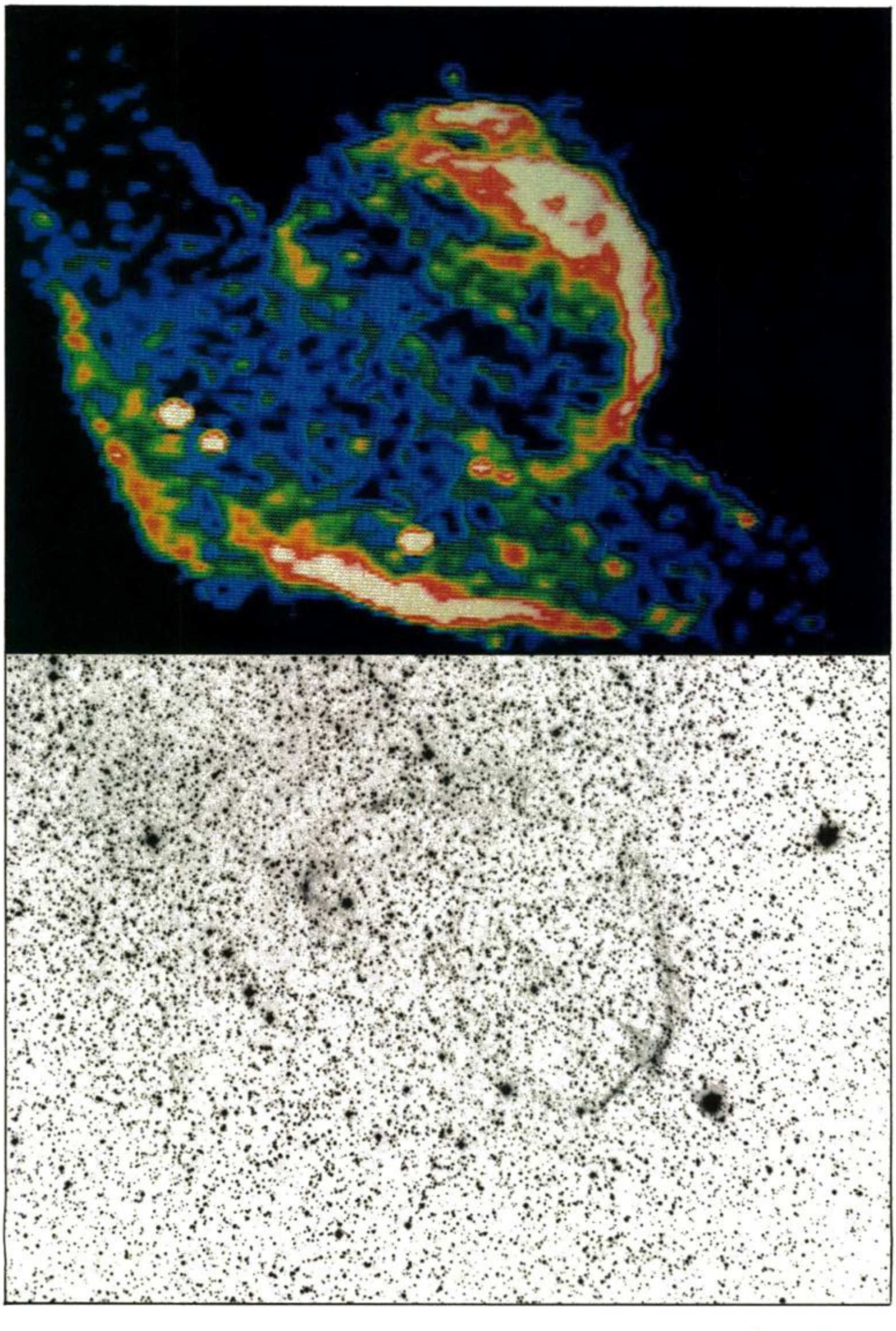
After the Uranus encounter, mission controllers hope that the craft will be in good enough shape and have sufficient propellant for an encounter with Neptune in 1989. After that, Voyager 2 — like its sister ship Voyager 1 — will continue its long, coasting flight out of the solar system into the depths of interstellar space.

## One Remnant or Two?

The radio source VRO 42.05.01 is a very unusual supernova remnant. While its eastern edge consists of a typical shell-type remnant, a strange irregular component makes up the western edge, apparently overlapping the eastern shell. Both the spherical and irregular "wing" components have spectra typical of supernova remnants, and both contain high-velocity filaments of gas. Since the two very different components appear to be the remnants of exploded suns, their appearance together in the sky invites the question of whether VRO 42.05.01 is the remnant of one supernova or two.

A group led by T.L. Landecker of Canada's Dominion Astrophysical Observatory examined the object in an attempt to determine its nature. Although it lies 16,000 light-years away, in the outer part of the Galaxy, its position makes it unlikely that the object is really two separate remnants superimposed along our line of sight. At any rate, this would not make the irregular wing component any easier to explain. "Even if it's considered a remnant on its own, separate from the shell," Landecker said, "it is unlike any other supernova remnant."

One possibility is that VRO 42.05.01 consists of the remnants of two supernova explosions that occurred in the same vicinity. If this is the case, then the larger wing component is the result of the first explosion, while the smaller shell component is the result of a second supernova. The two stars must have been in existence simultaneously, since supernova remnants are only observable for about 100,000 years.



**This false color radio map (top) shows the appearance of supernova remnant VRO 42.05.01 at 1420 MHz. The object is barely visible at optical wavelengths, as shown by the negative print (bottom) from the Palomar Sky Survey. The rounded eastern component and the irregular western component are so different that they could be two separate remnants. Photos courtesy T.L. Landecker, Dominion Radio Astrophysical Observatory.**

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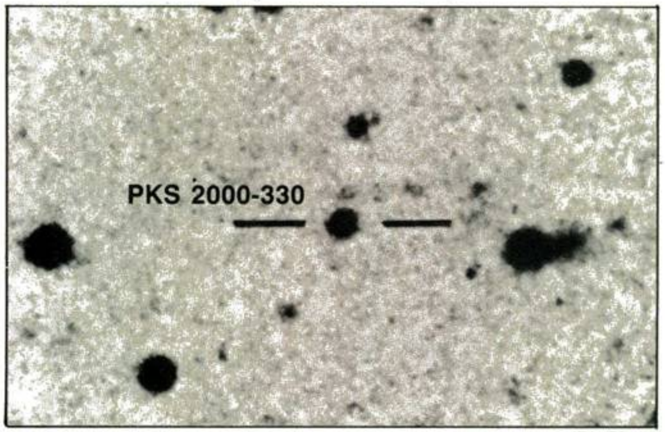
# ASTRONEWS

The stars may have been close together and may have exploded in sequence merely by chance, notes Landecker — although this scenario, too, leaves the bizarre shape of the first remnant unexplained.

The most likely interpretation of the object requires a special density distribution of material in the interstellar medium. Imagine that a star has exploded in a dense slab of gas. The shock wave from the explosion interacts with the dense gas to form the circular shell on the eastern side. But on the west side, the shock front breaks out of the dense gas and expands rapidly in a region of lower density. The westernmost portion of the wing component can thus be interpreted as the shock wave striking another dense gas cloud. Between the shell and the bright western ridge, the emission fades as the shock wave travels northwest to southeast between slabs of gas. According to Landecker, "The alignment of the brightest parts of the remnant may well indicate how the interstellar magnetic field is aligned with the slabs."



JPL Photo

## Farthest Quasar

Astronomers from the United States, Great Britain, and Australia have found a quasar more than 12 billion light-years away — the most distant object in the universe. Light now arriving at Earth from the object, named PKS 2000-330, began its long journey about two billion years before our Milky Way Galaxy was formed.

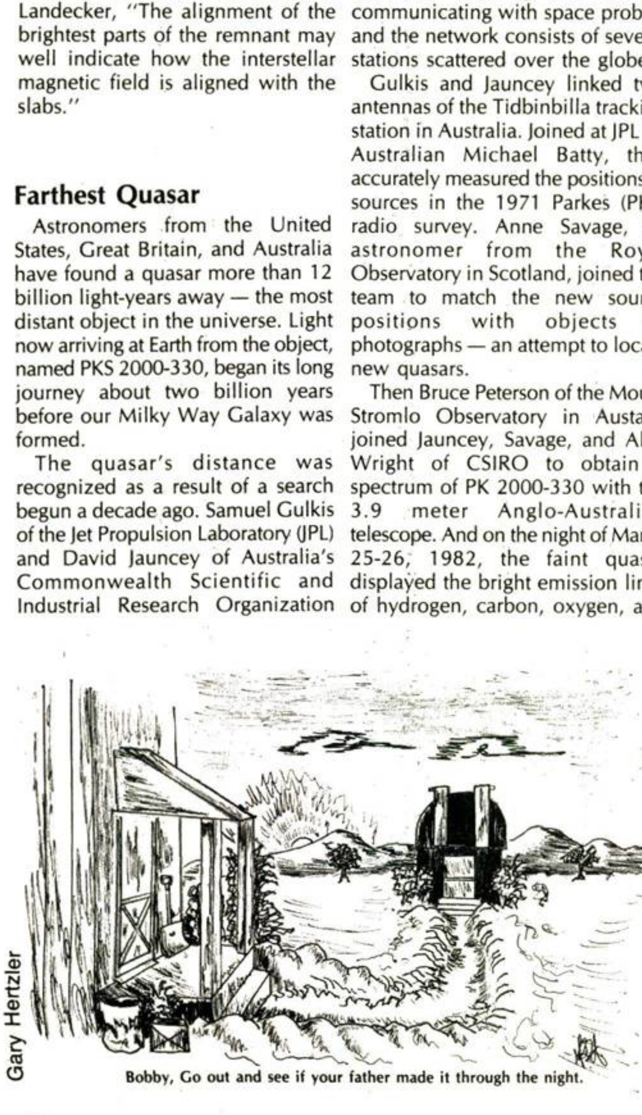
The quasar's distance was recognized as a result of a search begun a decade ago. Samuel Gulkis of the Jet Propulsion Laboratory (JPL) and David Jauncey of Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) suggested that the tracking antennas of NASA's Deep Space Network could be used to determine accurate positions of celestial radio sources. The antennas are normally used for tracking satellites or communicating with space probes, and the network consists of several stations scattered over the globe.

Gulkis and Jauncey linked two antennas of the Tidbinbilla tracking station in Australia. Joined at JPL by Australian Michael Batty, they accurately measured the positions of sources in the 1971 Parkes (PKS) radio survey. Anne Savage, an astronomer from the Royal Observatory in Scotland, joined the team to match the new source positions with objects in photographs — an attempt to locate new quasars.

Then Bruce Peterson of the Mount Stromlo Observatory in Austalia joined Jauncey, Savage, and Alan Wright of CSIRO to obtain a spectrum of PK 2000-330 with the 3.9 meter Anglo-Australian telescope. And on the night of March 25-26, 1982, the faint quasar displayed the bright emission lines of hydrogen, carbon, oxygen, and nitrogen — all shifted to far longer wavelengths than those expected from laboratory measurements. The displacement of the quasar's spectral lines is the greatest ever observed.

Edwin Hubble was the first to recognize the relationship between an object's redshift and its distance. The shift of emission lines to longer wavelengths is caused by the rapid motion of the source away from us. Hubble found that redshift — and thus recessional velocity — increased with distance from Earth.

The quasar's high redshift — 3.78 — places it 12 billion light-years from us, but even at this distance PKS 2000-330 is magnitude +19 — the most distant and most luminous object known. The previous record holder, called OQ 172, is thought to be around 11 billion light-years distant.



Bobby, Go out and see if your father made it through the night.

## A Bigger, Better Big Bang

A recent revision of the Big Bang theory suggests that the universe is $10^{100}$ times larger than its currently estimated size of about 12 billion light-years. According to Paul Steinhardt and Andreas Albrecht of the University of Pennsylvania, the new theory corrects some basic problems in the standard model of the creation of the universe — the Big Bang.

"There are various reasons why people have become uneasy with the standard Big Bang model," said Steinhardt. "When we look at our universe on the largest scales that we can observe, it is extremely homogeneous and isotropic. That is, we observe different parts of the universe, even widely separated ones, to be essentially the same." But according to the Big Bang theory, the most distant parts of the universe have never been causally connected — neither light nor any other possible interaction has had time to travel between widely separated regions.

Another source of uneasiness with the present model is the amount of matter in the universe. Measurements indicate that there is nearly enough matter for our universe to be "flat" — expanding ever more slowly without collapsing in on itself. But the standard Big Bang model offers no good explanation for this condition. In addition, there is no satisfactory explanation for the large fluctuations in density necessary for the formation of galaxies later on.

According to Steinhardt, unified theories of particle physics indicate that the universe must have changed phase as it expanded and cooled. Steinhardt believes that the universe must have been in a different phase when it first exploded, passing through a phase transition as it cooled — just as water changes to ice as the temperature drops.

In the first fraction of a second after the Big Bang, the universe was incredibly hot and expanded at the rate predicted by the standard model. This high-energy phase of the universe was analogous to the high-energy liquid state of water. The universe cooled as it expanded and eventually reached a point where the cool ("ice") state required less energy than the hot state — but an energy barrier kept the universe trapped in the hot state. This phenomenon is called supercooling. A more familiar example of supercooling occurs when extremely pure water is cooled below its freezing point without turning into ice.

As the universe expanded during supercooling, its density decreased and diluted the matter and radiation in the universe. But energy associated with the high-energy phase of the supercooled universe changed the steady, arithmetical rate of expansion (for example, 2, 4, 6, 8) to an exponential growth rate (2, 4, 8, 16). The density of the universe now decreased at an exponential rate, approaching that of a vacuum.

According to Steinhardt's model, the energy barrier now disappeared — the temperature decreased and the universe moved into its low-energy state. The transformation began so slowly, however, that the universe had time to undergo tremendous exponential expansion. At the end of the transition, energy stored in the hot phase was released by creating the matter and radiation that now exist, and the universe resumed an arithmetical rate of expansion.

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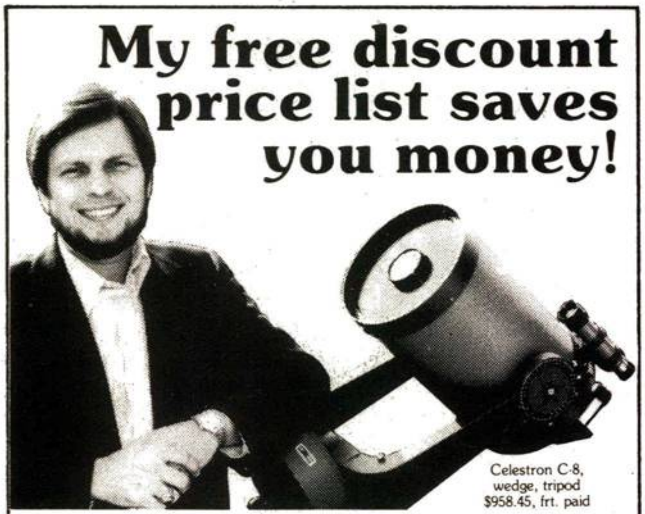

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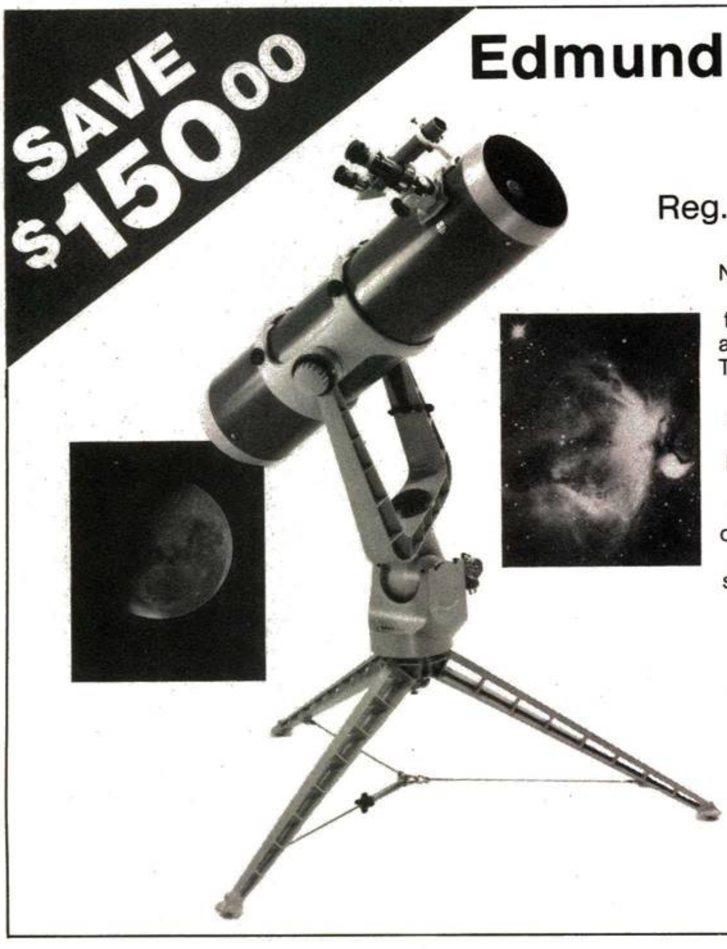

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# ASTRO NEWS

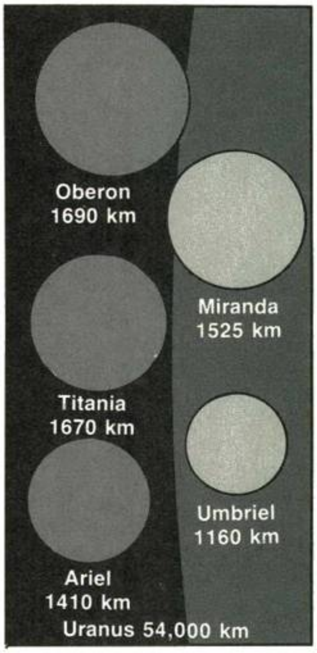
In the old Big Bang model, Steinhardt said, we thought we could detect the outer reaches of the universe at about 12 billion light-years. If his Hot/Cold Big Bang model is correct, however, the universe may be more than $10^{100}$ times larger than that predicted by the standard theory — the observable universe is but a small fraction of the whole. So the homogeneity of the visible universe should not be surprising. Before the phase transition, this small pocket of the universe was small enough to be causally connected, and the brief period of exponential expansion ensures that the pocket becomes large enough to encompass the observable universe. Interestingly, the model also allows other pockets — so far away that we may never be able to detect them — to be rather different from our own.

Steinhardt's Big Bang also leads to a universe that is necessarily flat, and it contains sufficient post-expansion density fluctuations to explain the origin of galaxies. "We can get away from thinking that the universe is pretty much the same everywhere," Steinhardt said. "An interesting point about this theory is that the universe was almost a vacuum at one time, with nothing that we could call matter or energy — all the matter and energy are produced at the end of the transition," he said. "What we call the universe," Steinhardt added, "is really produced from a vacuum in this picture. And that's very different from what we thought before."

## Uranus' Moons Measured

Using a combination of optical and infrared photometry, researchers at the University of Hawaii have measured the diameters of the satellites of Uranus more accurately than ever before. The technique, which has been widely applied to measuring asteroid diameters, assumes that the body is heated only by solar energy.

Every surface reflects some light, absorbs some light, and is warmed by the light it absorbs. If the surface is dark, or has a low albedo, it becomes warmer and emits more long wavelength infrared energy; if it is light in color, or has a high albedo, it is colder and gives off less infrared, but reflects more and is brighter in the visible part of the spectrum. Measurements of asteroid diameters and albedos made this way have been closely confirmed by other methods.



Uranus' moons turn out to be darker and larger than had been previously estimated under the assumption that their surfaces were covered with bright water ice.

The largest, Oberon, was measured as 1690 kilometers in diameter, with an uncertainty of 110 kilometers in the determination. Having an albedo of 22%, plus or minus 3%, it is the darkest of the uranian satellites — roughly medium gray in tone.

Titania is very slightly smaller at 1670 kilometers; with the 90 kilometer uncertainty of measurement, it could be bigger. Its albedo is 27%. Miranda follows, with a diameter of 1525 kilometers and a 60% albedo — the brightest of the uranian satellites by far. Then comes Ariel, at 1410 kilometers and 34% albedo, and finally Umbriel at 1160 kilometers diameter with a 23% albedo.

For comparison, Saturn's satellite Rhea is 1530 kilometers in diameter, and the albedos lie roughly midway between the albedos of Jupiter's satellites Ganymede and Callisto.

The low albedos of four of the uranian satellites suggest that their surface ices may be contaminated with dark particles as some of the jovian and saturnian satellites probably are. But the colder environment at Uranus means the chemistry and composition of the particles could be quite different than similar darkened surfaces in the jovian and saturnian systems.

Voyager 2 will fly through the Uranus system in 1986, and its TV cameras should be able to record the surfaces of these bodies in considerable detail. These measurements were made with NASA's 3-meter Infrared Telescope Facility on Mauna Kea.

# ASTRO CALENDAR

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| **February 18-20** | **International Union of Amateur Astronomers Regional Symposium.** Charleroi, Belgium. Contact: James J. Doyle, IUAA Councilor-Western Europe, 68 Rue de la Neuville, Bte 6, B6000, Charleroi, Belgium. |
| **March 5** | **Astrophoto V**, a one-day seminar treating all aspects of astrophotography. Moorpark College, Moorpark, California. Contact: John Byhoffer, 9406 Petit Circle, Ventura, CA 93004. |
| **March 14-18** | **14th Lunar and Planetary Science Conference** (professional meeting). NASA Johnson Space Center, Houston, Texas. Contact: 14th LPSC, Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058. |
| **April 22-25** | **National Congress of Astronomers**, Astronomical Society of Southern Africa — meeting canceled. |
| **May 9-12** | **6th Princeton Conference on Space Manufacturing**, co-sponsored by Space Studies Institute. Princeton University, Princeton, New Jersey. Contact: April Whitt, The Space Studies Institute, Box 82, Princeton, NJ 08540. |
| **June 8-12** | **Texas Star Party**, Fort Davis, Texas. Contact: T.S.P. '83, Dept. A, 2709 Colonial Dr., Carrollton, TX 75007. Phone (214) 242-4908. |
| **June 13-19** | **Joint Meeting of the Astronomical Society of the Pacific and the Western Amateur Astronomers**, on the Kona coast of the Big Island of Hawaii. Contact: Hawaii Meeting, A.S.P., 1290 24th Avenue, San Francisco, CA 94122. |
| **August 5-6** | **Stellafane.** Springfield, Vermont. Contact: Dennis di Cicco, 60 Victoria Rd., Sudbury, MA 01776. |
| **August 1984** | **6th World General Assembly of International Union of Amateur Astronomers.** Bologna, Italy. Contact Dr. Luigi Baldinelli, c/o A.A.B., Casella Postale 1630 AD, 1-40100 Bologna BO, Italy. |

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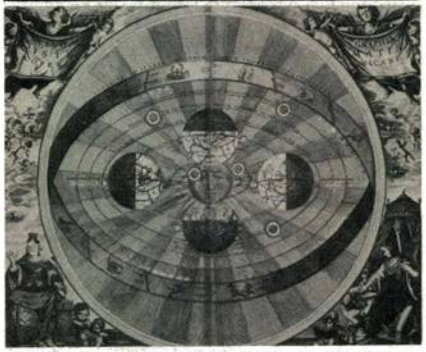

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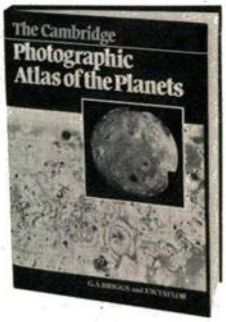
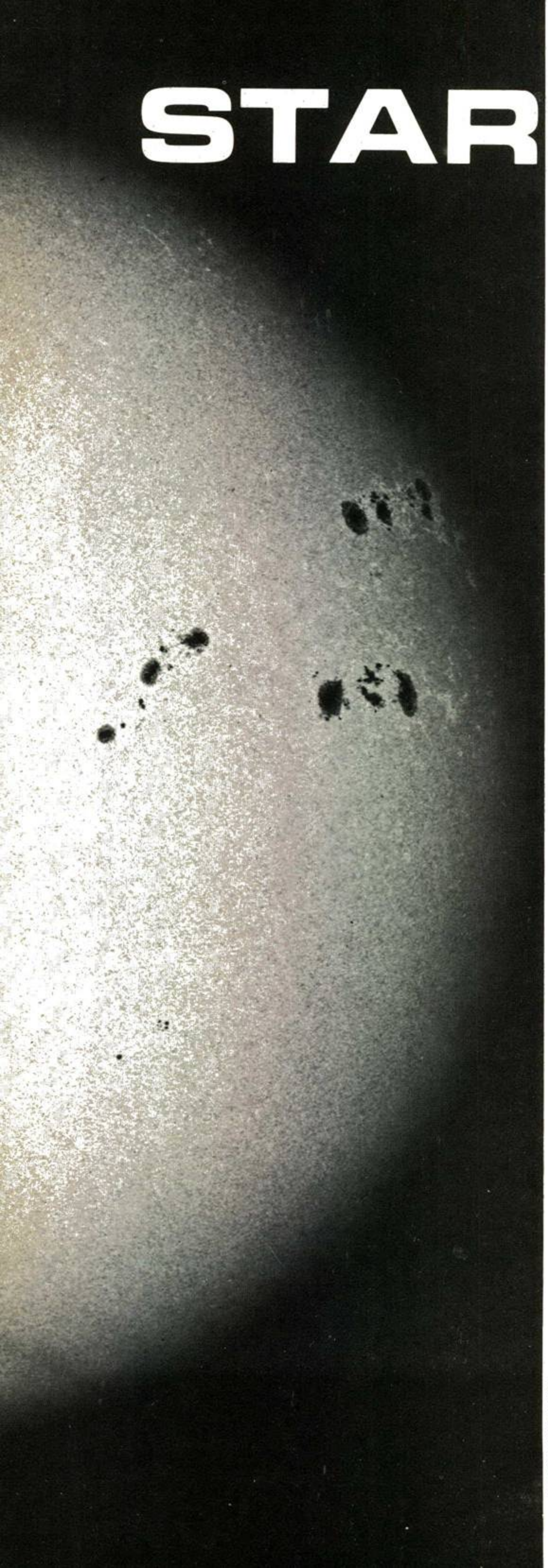


# STARSPOTS

### by Douglas Hall



Hale Observatories

Our Sun is a star — and not a very unusual one. Compared to other suns in the Galaxy, ours is a run-of-the-mill dwarf of average mass, brightness, and temperature. In fact, the Sun's most distinctive characteristic is its proximity to Earth — it is the only star close enough to allow astronomers to study the dynamic structure of a stellar surface. Astronomers routinely observe a wide range of activity on the Sun's surface, from plasma-gushing prominences to powerful flares that spray solar material into space. However, the most easily recognized solar features are sunspots. Occasional spot groupings are even large enough to be seen with the unaided eye. Theophrastus, a philosopher in ancient Greece, may have observed the small dark splotches on the Sun, but the realization that they are actual features on the Sun — not high-flying birds or other terrestrial phenomena — had to await the invention of the telescope.

Sunspots are temporarily disturbed areas in the Sun's photosphere. They appear dark because they are much cooler than the surrounding gas. Small groups of sunspots — usually no larger than 50,000 kilometers, or about four times the Earth's diameter — march in unison across the Sun as it rotates. They contain magnetic fields thousands of times more powerful than the Earth's, and sometimes emit intense, variable radio "noise."

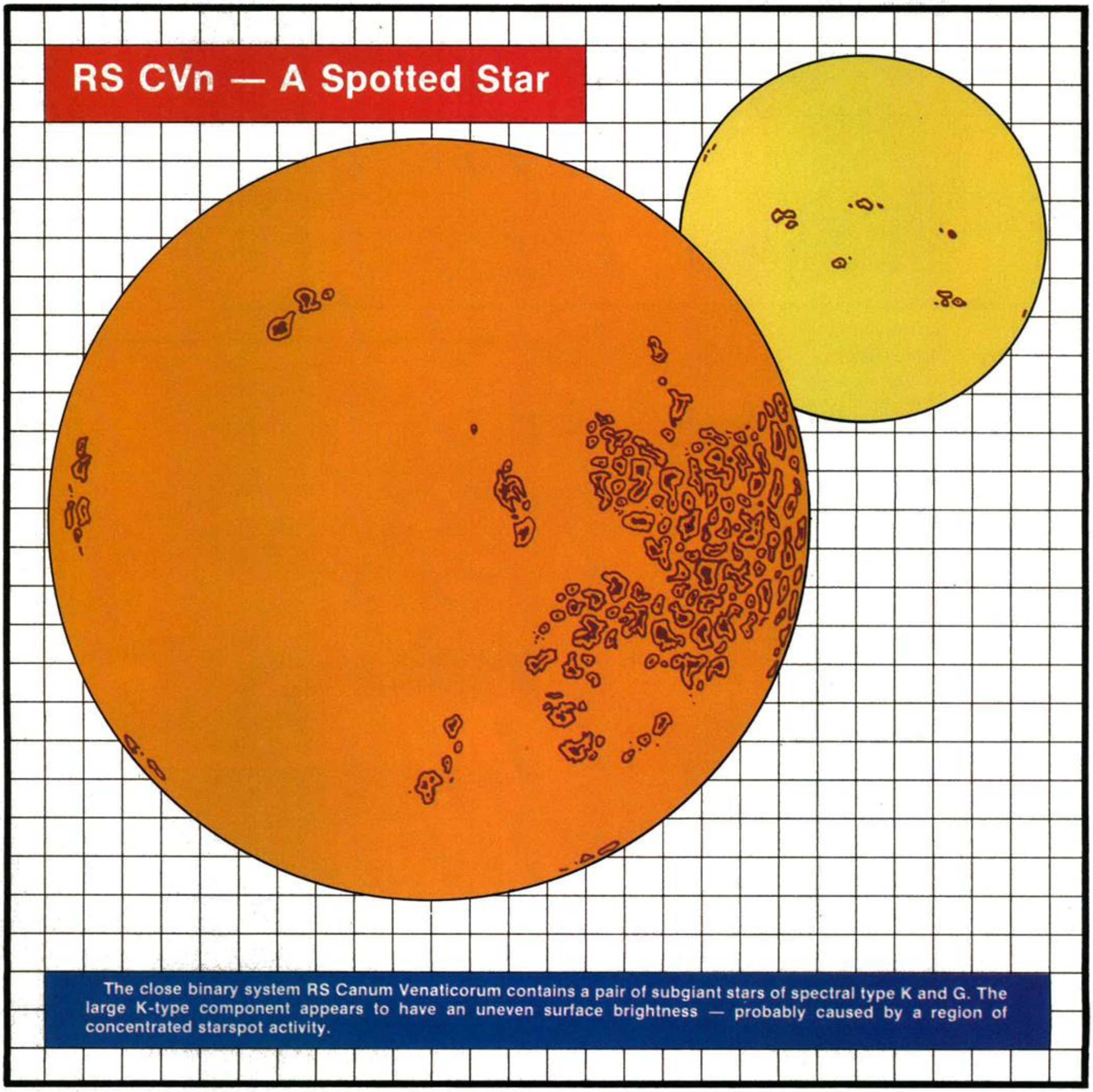
Sunspots are not always present on the Sun — their numbers rise and fall in a somewhat irregular 11-year "sunspot cycle," and sometimes the cycle itself disappears. The acknowledged discoverer of solar spots, Galileo Galilei, was forced to recant his belief in them. Since church authorities believed that the Sun was a perfect sphere, Galileo's claim of solar blemishes was clearly a heresy; under pressure from the Inquisition, he renounced his belief in a spotted Sun in 1633. This tragedy was followed by irony: between 1645 and 1715, spots on the Sun all but disappeared. The 70-year absence of spots is called the Maunder minimum, and its cause is still not understood. When sunspots did return, however, eighteenth-century astronomers accepted their reality without hesitation. Solar research was well on its way when Heinrich Schwabe recognized the 11-year cycle of sunspot activity in 1843.

Since the Sun is a fairly typical star — host to a variety of activity — might the same processes at work on the Sun also be at work on other stars? More specifically, do other stars have spots?

Surprisingly, starspots were hypothesized only a few decades after Galileo's setback. In 1667, French astronomer Ismael Boulliau explained the light variations of the star Omicron Ceti (Mira) as due to one dark hemisphere — so the starspot hypothesis was the first attempt to explain the variable brightness of a star. We now know that Boulliau's suggestion is incorrect — an entirely different mechanism causes the variation of Mira's light.

Nevertheless, the starspot hypothesis remained popular for the next two centuries. Scientists used it to account for all sorts of stellar variability that could not be explained as stellar eclipses. Even cycles of starspot activity, similar to the 11-year sunspot cycle, were invoked to explain the large increases in brightness of some stars. We now know these "temporary stars" as novae and supernovae.

In 1890, Harvard astronomer Edward Pickering analyzed the light curves of short-period variable stars by means of Boulliau's starspot model. We now know that the stars in Pickering's sample were really a mixture of Cepheid variables (stars that change brightness by pulsating) and Beta Lyrae-type variables (close eclipsing binary stars). So the popularity of the starspot hypothesis



RS CVn — A Spotted Star

The close binary system RS Canum Venaticorum contains a pair of subgiant stars of spectral type K and G. The large K-type component appears to have an uneven surface brightness — probably caused by a region of concentrated starspot activity.

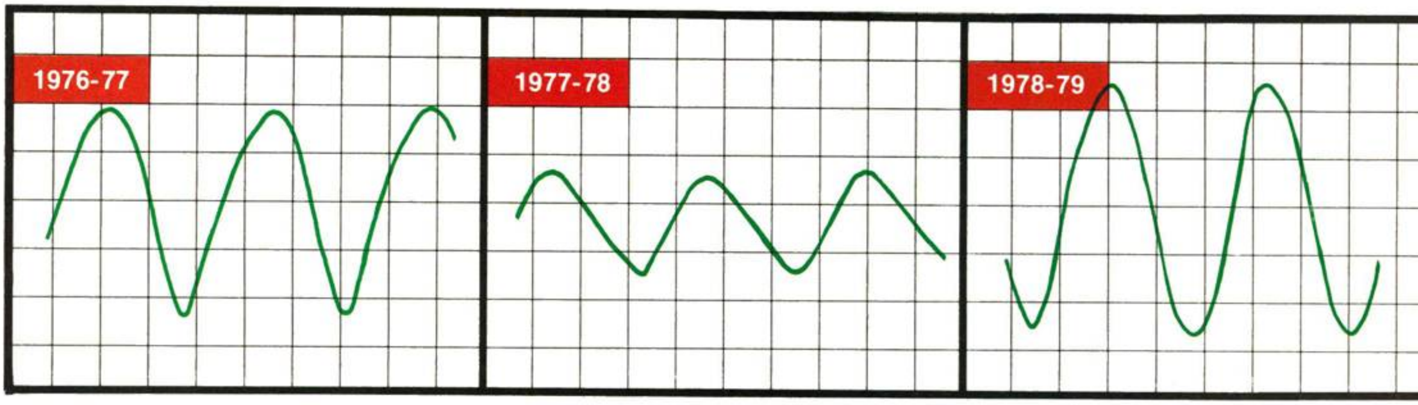
faded rapidly by the turn of the century — not because it was unbelievable or even unlikely, but because it had been applied to stars that changed their light output for entirely different reasons.

It took nearly half a century before anyone used starspots to explain the variability of stars that are actually spotted. In 1947 and again in 1952, Gerald Kron explained some peculiar light variations in several eclipsing binary stars. The large brightness fluctuations of these stars — AR Lacertae, YY Geminorum, RS Canum Venaticorum, and RT Andromedae — occur when a faint star passes between Earth and a brighter star. But Kron was primarily concerned with small cyclic variations that occur outside the eclipses. Now variables of this type are called RS CVn stars, after the prototype star RS Canum Venaticorum. Ten years later, other astronomers began to notice slow light variations in certain dwarf stars of spectral type K and M, also known as flare stars, so Boulliau's starspot model was invoked. These variables are designated "BY" after BY Draconis, the prototype spotted flare star.

For a time, the evidence for stellar spots was largely circumstantial — but no other hypothesis explained the data. No one had actually seen spots or provided positive proof that they existed. Within the last few years, however, the evidence has overwhelmingly supported the idea of starspots. Our Sun is no longer unique as a spotted star.

What is the evidence? The most elegant and decisive proof came in 1979. Steven Vogt of Lick Observatory obtained a spectrum of the RS CVn-type binary II Pegasi at both maximum and minimum brightness and subtracted the two numerically. Logically, the result of this spectral subtraction had to be the spectrum of whatever was making one hemisphere fainter — and once its spectrum was known, the temperature of the dark hemisphere could be determined. Vogt's result indicated that the surface temperature of the star's faint region was 3,300 degrees Kelvin. Since researchers knew that II Pegasi's temperature was normally 4,500 K, Vogt had proved the existence of a cooler, and therefore darker, region.

Are other classes of stars spotted? In 1965, the German variable-star expert Cuno Hoffmeister suggested that T Chamaeleontis, RY Lupi, RU Lupi, and AK Scorpii — four T Tauri-



type variables — had spotted surfaces. T Tauri stars are very young stars, still contracting toward the main sequence. Many different mechanisms could conceivably explain their light variations, but no one has yet disproved Hoffmeister's suggestion of an unevenly spotted, rotating star.

Since astronomers now believe that some stars have spots, what are starspots like? In particular, how might starspots compare to the more familiar sunspots?

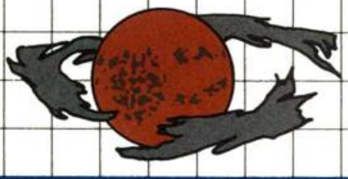
Astronomers have to admit that there are no direct answers — yet. But we think we have a pretty good picture — indirectly obtained — of what starspots are like. We know, on the basis of the light variations, that spots can cover up to 20% of the total surface area of a star. We also know that these dark regions are not distributed uniformly or randomly around the star, but tend to occur in just one hemisphere. Up to 40 percent of a star's visible hemisphere can be spot covered. In contrast, no more than 0.5 percent of the Sun's surface area is covered by spots at any one time — even during the maximum of its 11-year sunspot cycle.

On some stars, the spot regions lie near the stellar equator, while on others the spots lie as far as 65° from the equator. In many stars the light variations can be explained by a single dark region, while on other stars the asymmetrical nature of the variations requires at least two regions. We also know that the temperature difference between the dark region and the surrounding photosphere can be as little as 700 K or as great as 2000 K (the same as sunspots), depending on the star. Furthermore, an individual dark region on a particular star can be extremely long-lived. Some have existed without disruption since they were discovered. The dark region on λ Andromedae seems to have been there at least since 1933 — almost a half century. It remains fixed on the surface of the star, rotating with it.

In cases where the spotted star belongs to a binary system, the rotation period is quite close to the orbital period, a situation known as synchronous rotation. (Our Moon rotates synchronously in its orbit around the Earth.) Curiously, though, the star rotates about one percent faster than the orbital motion. A dark region lined up with the companion star in one year will gradually move around the spotted star and not be lined up again until about ten years later. This slight departure from synchronous rotation may be related to the differential rotation we see on the Sun, which causes spots at different latitudes to rotate at slightly different rates. There have been a few documented cases where the dark area, while staying in the same place, produced much more light variation in one month than it had just a couple of months before. We don't know whether the dark region suddenly became larger or cooler or if the density of spots within the region increased. On stars with two dark regions, yearly photometry generally shows changes in their relative positions —the spots gradually drift closer together or farther apart.

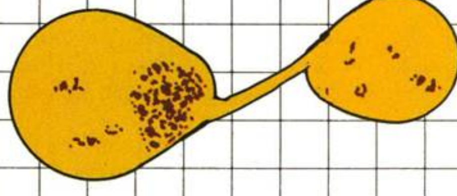
There are exceptions to the rule of synchronous rotation. The star BY Draconis, prototype of the spotted flare stars, regularly varies its light output every 3.8 days, but its companion has an orbital period of 5.98 days — hardly synchronous rotation. One good reason for this discrepancy is that the the spotted star's companion follows a highly eccentric orbit, which makes

## Spotted Stars What's in a Name?



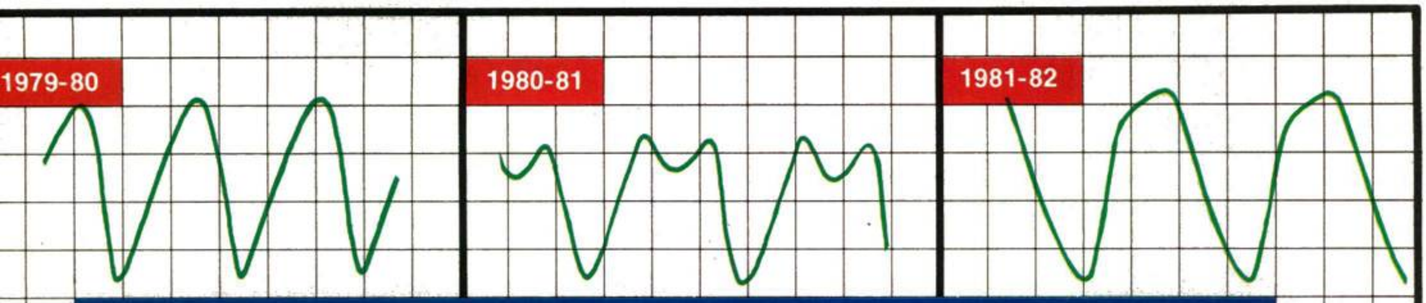
**T Tauri Stars**

Young, low mass stars (probably no older than a million years and no more than about twice the mass of the Sun) associated with interstellar gas and dust and believed to be in the process of gravitational contraction on their way to the main sequence. One of the characteristics of these stars is the variability of their light at all wavelengths. T Tauri itself is a dwarf of spectral type K and is embedded in a cold gas cloud.

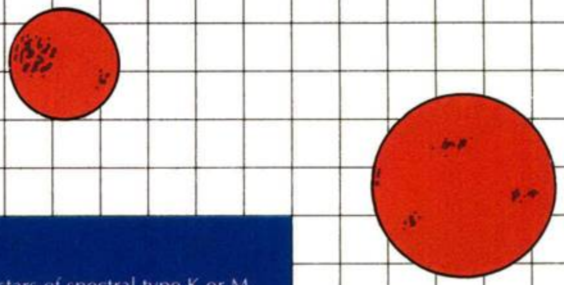


**W Ursae Majoris Stars**

A large class of "contact" binaries with orbital periods of no more than 0.6 days. They are all of spectral type F or G and have nearly equal surface temperatures. The stars are intrinsically faint and orbit so close to one another that they share a common envelope of material. The spectra of W UMa stars indicate mass exchange.

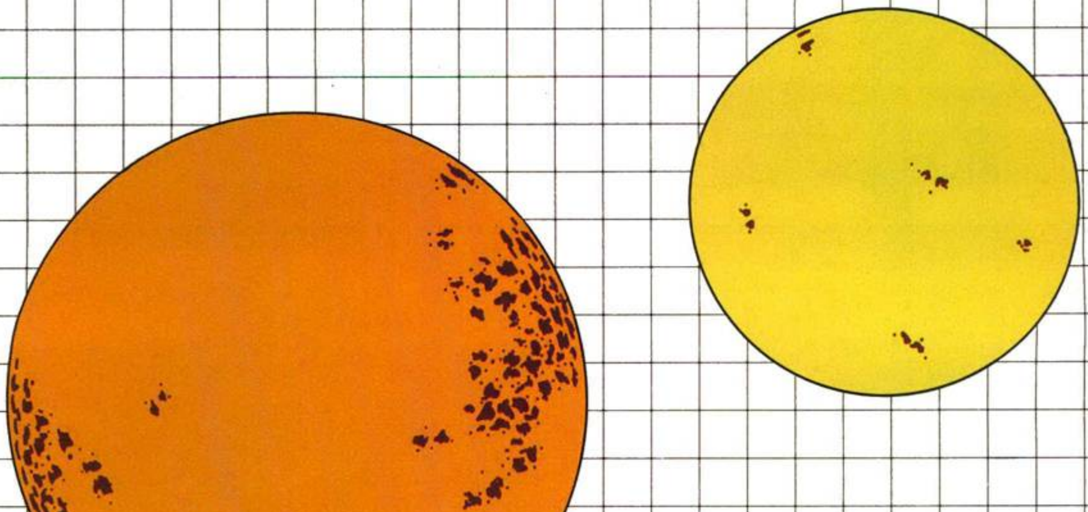


**The strongest evidence for stellar spots lies in the star's light curve. Here, λ Andromedae shows different light curves each year, as the dark region on its surface changes size and position.**



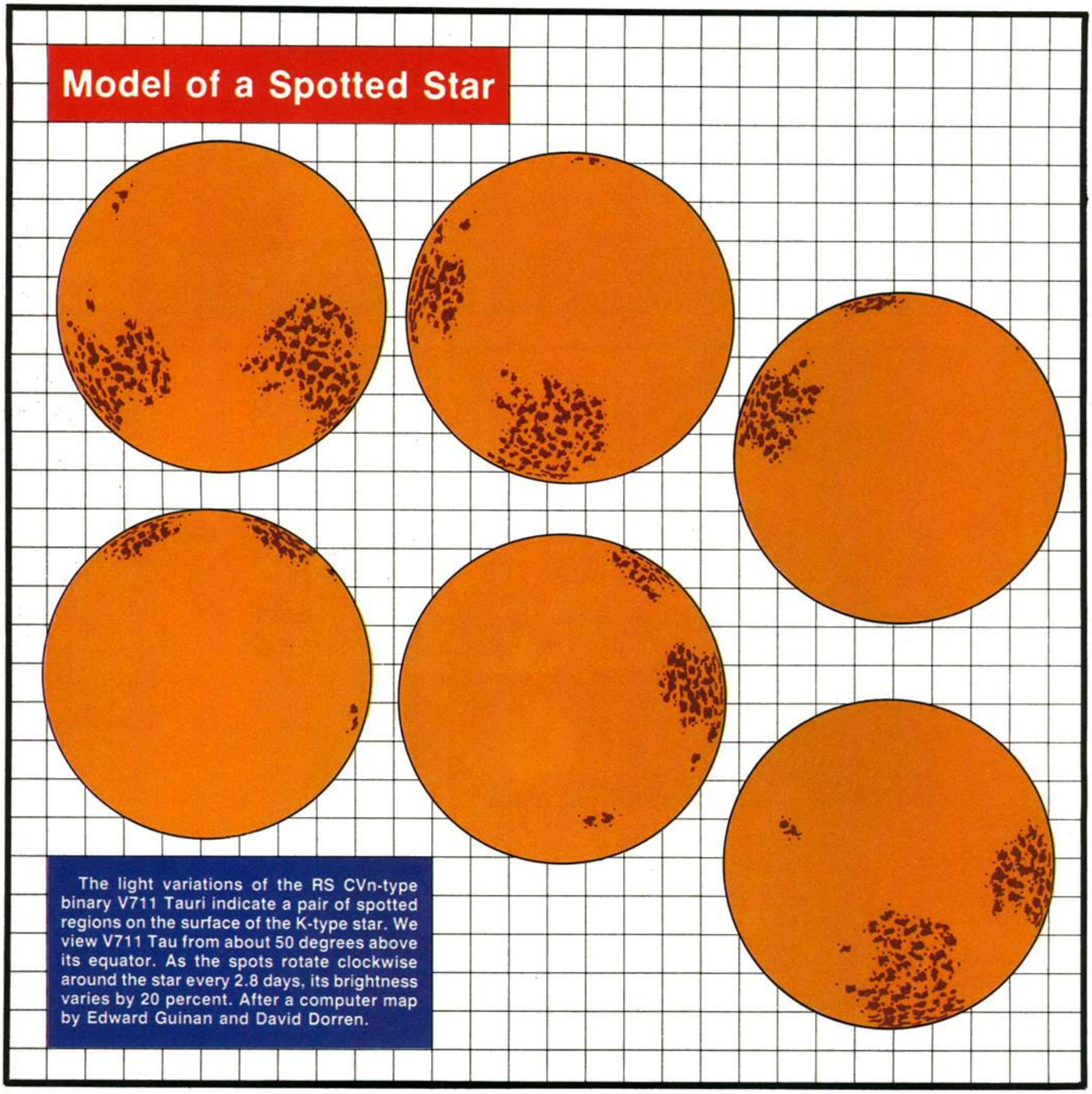
**BY Draconis Stars**

Rapidly rotating single and binary stars of spectral type K or M. The prototype star, BY Dra, is a dwarf flare star about 51 light-years distant. Its light output varies every 3.8 days and the orbital period of the companion is 5.98 days. The changing light of BY Dra is thought to be caused by the non-uniform surface brightness (spots) of the K-M dwarf component.



**RS Canum Venaticorum Stars**

Close binaries with a hot subgiant component of spectral type F or G and a cooler subgiant component of about type K. Orbital periods range from a couple of days to a couple of months. The stars appear to have evolved off the main sequence but have not yet begun mass exchange. Many RS CVn stars have variable radio emission, and many are X-ray emitters.



Model of a Spotted Star

The light variations of the RS CVn-type binary V711 Tauri indicate a pair of spotted regions on the surface of the K-type star. We view V711 Tau from about 50 degrees above its equator. As the spots rotate clockwise around the star every 2.8 days, its brightness varies by 20 percent. After a computer map by Edward Guinan and David Dorren.

synchronous rotation more difficult to attain. For RS CVn-type systems, the only known exception to synchronous rotation is λ Andromedae, which has an orbital period of 20.52 days and a rotation period of 53.95 days.

In most stars studied long enough, the average brightness level changes too. Lee W. Hartmann studied BD+26°730 by analyzing old photographs taken at Harvard College Observatory since the late 1890s and saw the average brightness vary gradually over a range of 0.5 magnitudes. This suggested the possibility of a cycle similar to the Sun's 11-year cycle. Such cycles may not exist in these heavily spotted stars, though. The huge dark regions may be caused by far different mechanisms than those on the Sun — after all, they cover 100 times more surface area than sunspot groups and have lifetimes measured in decades rather than months. These heavily spotted stars may experience the stellar equivalent of the Sun's Maunder minimum, but we need extensive systematic observations to be sure.

Is the dark region one large spot, with a giant umbra and penumbra, or does it consist of many smaller sunspot-like spots? As yet, no one knows what starspots look like, but observations now under way will provide valuable clues. The orbital companions of some spotted stars pass in front of the dark region. Astronomers will be able to determine the actual configuration of the starspots by observing these events at high resolution.

What causes these large dark regions? Once again, there are more questions than answers. We know, however, that the types of stars that are spotted have outer layers that transfer heat through convection, the movement of large amounts of mass. Our Sun has convective outer layers, and we know the sunspot phenomenon is intimately related to convection. Most of the spotted stars are cooler and/or larger than the Sun — two factors which make for a deeper convective zone. These stars also all rotate considerably faster than do otherwise similar stars. The recipe for spots seems beguilingly simple: a convective outer layer (the deeper the better) and rapid rotation.

So far, we've discussed extreme spot activity: dark regions covering 100 times more area than sunspots do and lasting 100 or 1000 times longer than sunspot groups. But spotted stars like RS CVn, BY Dra, and W Uma are active in virtually all of the ways the Sun is, only far more so. Their chromospheric activity,

## Spotted Stars in ASTRONOMY

**Flare Stars**

"Flare Stars," Anthony J. Nicastro, June 1981

**W UMa Stars**

"Contact Binaries: Stars that Touch," Ken Croswell, December 1982.

**Sun**

"The Case of the Missing Sunspots," Mary Martin DeLancy, February 1981.

"Solar Magnetism: A New Look," Leon Golub, March 1981.

"A New Look at the Nearest Star: The Solar Maximum Mission," James Ryan, May 1981.

"What Heats the Solar Corona?" Leon Golub, September 1982.

"Solar Prominences," Philip A. Stahl, January 1983.

judged by the strength of telltale emission lines in the spectrum, can be 100 times stronger. Their X-ray emission, measured recently by orbiting satellite observatories like HEAO-1 and Einstein, is 10,000 times more intense because of a stellar corona far denser and hotter than the Sun's. The winds from these stars, analogous to the solar wind that blows comet tails, are also about 10,000 times stronger. And the flare-like bursts of radio waves can be a a hundred million times more intense.

For a time many astronomers thought that the key to spottedness and intense activity was binarity. But Bernard Bopp, a University of Toledo astronomer, showed that not all BY Dra variables are in binaries — although they all rotate rapidly. It seems that binarity is important only indirectly: as a mechanism for making the spotted star rotate rapidly. Forced to rotate synchronously in a relatively short-period system, binary BY Dra stars spin much faster than most otherwise similar single stars. The solitary BY Dra variables presumably rotate very rapidly because of their youth — they haven't yet lost the excess spin acquired during the contraction of stellar formation.

But how do deep convection zones and fast rotation lead to spot activity? Astronomers commonly use the solar dynamo theory to explain sunspots and the solar cycle, and Steven Shore of Case-Western Reserve has applied it to spotted stars. This model assumes that the Sun's general magnetic field resembles a bar magnet, with magnetic lines of force running north and south. The Sun's differential rotation stretches these field lines into long loops that run east and west, and the lines become more tightly wrapped with each solar rotation. Eventually, magnetic field lines burst through the Sun's surface. The breakthrough point is marked by a sunspot, and the point where the field lines re-enter the surface has a spot of opposite polarity. This produces the familiar sight of a sunspot pair underneath a giant loop prominence. The progressively tighter winding of field lines causes the magnetic loops to burst through the photosphere at progressively lower solar latitudes. This explains why sunspot groups appear at high latitudes early in the 11-year cycle, but near the equator as the cycle comes to an end. Both the Sun and the more heavily spotted stars, however, need more intensive theoretical investigation before we can claim to understand the phenomenon of spots.

What will bring about a better model of spotted stars is more observations — but the key will be perseverance. We must learn the patterns of behavior, rules, and interlocking periodicities in order to understand what makes some stars so spotted. Researchers must define the light curve of a given spotted star at least once each year; a gap of a single year can obscure a pattern or break a thread of continuity. No astronomer today can predict what the light curve of any RS CVn or BY Dra star will look like next year. The battle to understand starspots has just begun.

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*Douglas Hall is a professor of astronomy and physics at Vanderbilt University in North Carolina. He is also a researcher at Dyer Observatory, involved in the photoelectric photometry of peculiar binary stars, and a founder of the IAPPP.*

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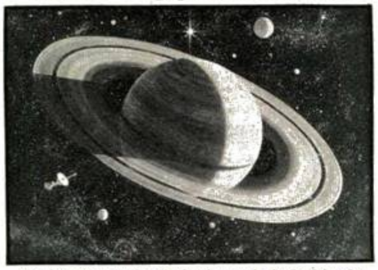

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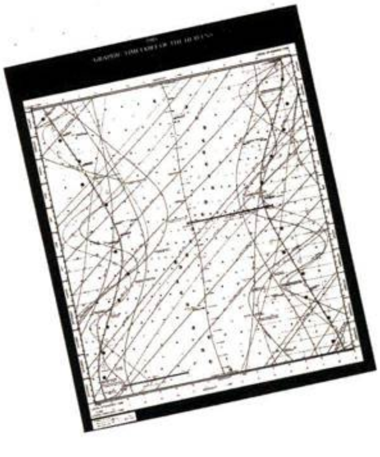

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# off-axis guiding: pain or panacea?

photography in astronomy

by
**Steve Reed**

Many would-be astrophotographers are shocked to learn that there's more to deep-sky astrophotography than attaching a camera to the telescope and turning on the clock drive. Tiny inaccuracies inherent in the gear systems of all clock drives, polar misalignment, short-term power variations, and atmospheric refraction all combine to cause tracking errors during the many minutes that exposures run. To get perfectly crisp photos with round star images, astrophotographers must monitor how well the drive is tracking and make manual adjustments to keep the telescope on target.

In principle, at least, this isn't difficult: to determine both the direction and size of the adjustments, you observe a star near the object being photographed with a high-power eyepiece that has an illuminated crosshair reticle. The direction and speed of the star's drift give you the cues you need to make the necessary tracking corrections.

There are two standard ways to image a guide star when the main telescope is being used for photography: a separate guide scope or an off-axis guider.

### Guide Scopes

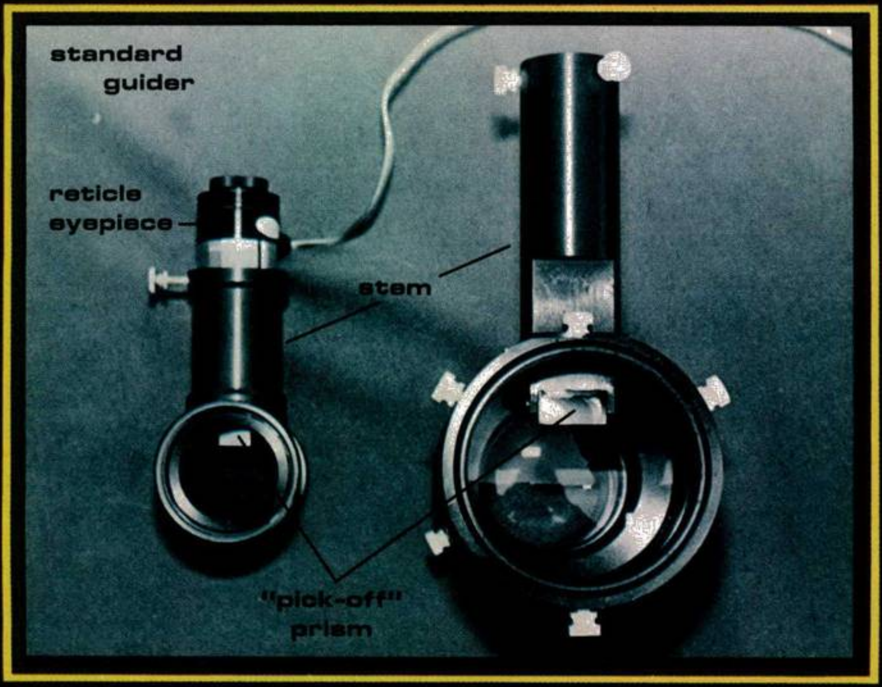
A guide scope is an auxiliary telescope attached to the main telescope by some sort of adjustable bracket. The bracket allows the guide scope to be aimed independently of the main telescope — which is, of course, occupied with taking the picture. The primary advantage of a separate guide scope is that it makes selecting a guide star very easy. Nor is this just a matter of convenience: guiding is far more accurate with a bright guide star — and bright stars are easier to find and set on with a separate guide scope.

In addition to keeping the guide star precisely centered on the crosshairs, accurate guiding also requires that the guide scope's optical axis remain fixed relative to that of the main scope — and there's the rub. There aren't any commercially-made instruments available to the hobbyist that will consistently deliver a well-guided photo when used with a separate guide scope. They're *all* flexure-prone. Most were designed for visual use and often lack the extra sturdiness required for photography. Guidescopes on these instruments are an afterthought, sometimes offered in response to consumer demand. Responsible companies will generally add a note or disclaimer regarding flexure with these "add-ons" in their instruction manuals or in the fine print of their catalogs.

The amount of flexure we're talking about can be very small — as little as a few thousandths of an inch. What's worse, you probably won't see or hear the tiny movement when it happens and the problem won't appear until you process your film. Then you'll discover that a very slight flexure undid all your careful guiding — and smeared what might have been pin-point star images into little ovals, lines, or "double stars."

This movement can also occur when your telescope's main optics are loosely mounted, as they usually are in reflectors and catadioptric scopes. In a reflector, a loose mirror is relatively easy to correct by re-mounting it more securely or wedging it into place — just don't lock it so tight that its figure is affected. Movement is almost impossible to correct in a catadioptric scope because it is designed to be focused by moving one or more of the optical elements — usually the primary mirror.

The venerable refractor is probably the least flexure-prone of any scope because its optics are securely mounted in a metal tube — but refractors are seldom used by hobby-astrophotographers because of their relatively slow f/ratios. When they are used as guide scopes, however, providing the focuser mechanism is "tight," flexure is minimal and their long focal lengths easily provide high powers



necessary for guiding.

Movement can also occur at the secondary mirror of a reflector. The secondary must be securely mounted in its cell, and the spider that positions it within the tube usually needs substantial beefing-up to keep it from moving during the exposure. With catadioptrics, movement of the secondary often isn't a problem because it is firmly attached to the securely-mounted corrector lens.

Since most reflectors are attached to their equatorial mount with clamp rings that grip the tube near its middle, the tube itself can sag from its own weight. You can largely correct this by substituting a heavy-gauge aluminum tube and/or by widening the cradle so that one ring grips the tube near the secondary mirror and the other near the primary. Most catadioptric scopes have such stubby metal tubes that flexure of this type is not a problem.

Another place movement frequently occurs is where the guide scope attaches to the main scope. The mounting brackets should be heavy-duty and widely spaced. But beware: often, the more complicated or fancy the coupling, the more flexure-prone it is.

In summary, you'll probably find you need to rework reflector and catadioptric scopes quite a bit before you get satisfactory results when using a separate guide scope with them.

### Off-Axis Guiders

An off-axis guider neatly avoids these movement-and-flexure problems because it uses the same optical system for photographing and guiding. It does so by means of a small "pick-off," usually a prism or mirror, which lies at the edge of the field and diverts the image of a star to the guiding eyepiece. The advantage is obvious: should any shifting of the optics or tube cause the image to move, you'll see it immediately and can make corrections.

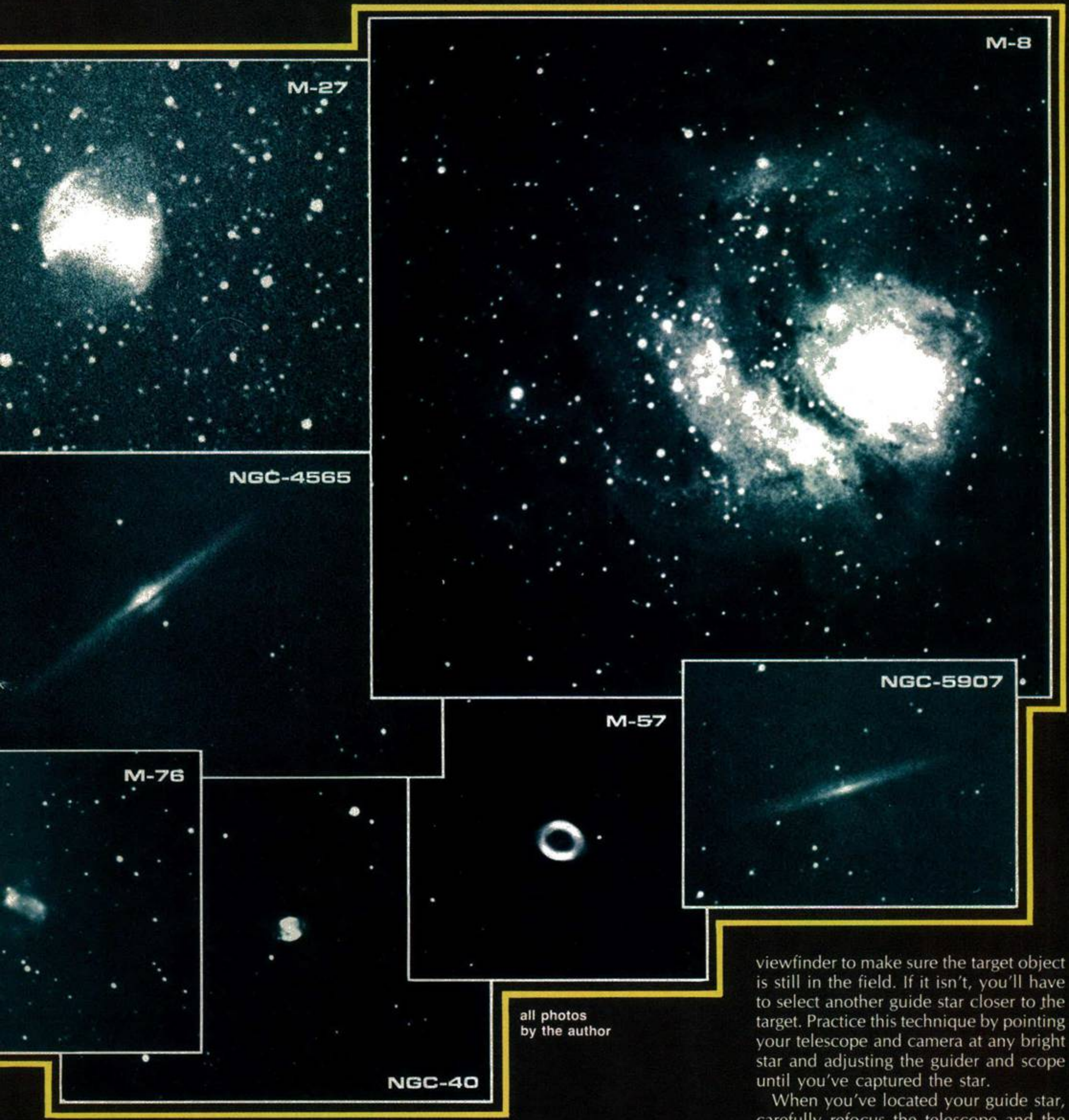
But even off-axis guiders aren't foolproof because they can't detect any movement that takes place *behind* the pick-off prism. For example, if the guider eyepiece were to shift position slightly, an apparent motion would result, so you'd go to correct it — and promptly blur what had been a perfect image on the film. Likewise, if the camera or its adapter ring were to shift during the exposure, you'd get trailed images even though in the guiding eyepiece all appeared to be going well. The remedy in both cases is to check all the elements before you start the exposure and tighten them securely.

A more annoying disadvantage of off-axis guiders is that your choice of guide stars is limited to the stars that lie in a narrow ring around your target object. Often, the only stars available are none too bright — or are positioned so you can't center the object in your picture. Moreover, with catadioptric scopes, the design is such that less light reaches the edge of the field. Since this is precisely where the off-axis prism lies, the apparent brightness of any guide star is thereby diminished.

Recently, some accessory manufacturers have designed off-axis guiders that minimize these disadvantages. Camera orientation and guiding eyepiece adjustments can be made independently. This provides a significant improvement over standard guiders. Off-axis guiders are now available commercially for reflecting telescopes, too. One make of guider fits into a standard 2" I.D. focuser and is probably the easiest way for reflector owners to "go off-axis."

But any potential user should bear in mind that my breezy statement about small prisms at the edge of the field diverting a star image gives you no appreciation for the difficulty and frustration sometimes involved in actually locating the star — in fact, it's the main reason why many with off-axis guiders wonder why they didn't beef-up their telescopes and install a separate guide scope!

The key to finding a guide star easily lies in always aligning the long dimension of the 35mm frame perpendicular to the off-axis guider's "stem," the tube the reticle eyepiece slips into. When you do this, the off-axis prism will be just outside the field-



all photos
by the author

of-view at bottom center as seen through the camera's viewfinder. If you're using a telecompressor lens, the pick-off prism will appear inside the field-of-view near bottom center. With the specially designed "giant" off-axis guiders, the prism will remain just outside the field at bottom center even with a telecompressor.

From experience, I suggest you take an exposure by locating your subject, attaching the guider to the scope, aligning the camera frame's long dimension perpendicular to the guider's stem, and focusing the telescope. Then scan the camera's field-of-view for the brightest star near your target object, and rotate the guider body until the star appears at bottom center of the field-of-view. Next, use the telescope's slow-motion controls to move the star straight down from bottom center until the prism intercepts it and it appears in the guiding eyepiece. (When scanning, use a low-power, wide-field eyepiece, instead of your high-power guiding one.)When you have the star centered in the field, switch to your reticle-equipped guiding eyepiece.

At this point, recheck the camera viewfinder to make sure the target object is still in the field. If it isn't, you'll have to select another guide star closer to the target. Practice this technique by pointing your telescope and camera at any bright star and adjusting the guider and scope until you've captured the star.

When you've located your guide star, carefully refocus the telescope and the illuminated reticle eyepiece, orient the crosshairs as you like, and clamp everything in place.

Now it's up to you. With all the instrumental uncertainties under control, a good job of guiding will guarantee that your photos will have crisp, round star images — or at least as good as the night's seeing allows!

---

*Steve Reed is a quality assurance representative at Rockwell International, Anaheim, California. He has been an astrophotographer for many years.*

# the backyard astronomer

## canis major

### Mercury

This month will see the completion of the apparition of Mercury that began in January. On February 1, Mercury will be a +0.4 magnitude dot of light, 7.8″ of arc across and 44% lit. Look for it about 7° high in the east-southeast 45 minutes before sunrise.

From this peak elevation, the planet will sink lower day by day until it disappears into the glow of morning twilight just before the end of the month. Greatest elongation from the Sun (26°) comes on February 8 at 20h UT.

The Moon, a slender crescent, will pass 2° south of Mercury on the morning of the 10th, giving telescope owners a chance to scan back and forth between the two, and astrophotographers a ready-made "pretty picture" to shoot.

### Venus

Venus' elevation in the evening sky will nearly double during February. Nine degrees high (45 minutes after sunset) on February 1, it will be almost 18° high by the 28th.

On the evening of the 18th, Mars (whose day-by-day path is descending slowly toward the horizon) will lie some 32′ north of Venus. Venus will be at magnitude −3.4, Mars at +1.4; Venus' diameter will be 11.3″ of arc, Mars' 4.2. In phase, they will both look very round: Venus 91% lit, Mars 98%.

### Mars

Aside from its conjunction with Venus on the 18th, Mars at present offers little to the telescope viewer. Over the course of the month, Mars' distance from Earth will increase by almost 16 million kilometers, from 323.1 million km to 338.9 million km. This means that only the largest markings on its surface can be discerned.

**Three craters lie along the terminator; from bottom up, they are Ptolemaeus, Alphonsus, and Arzachel. Note the dimpled "palimpsest" craters on the flat floor of Ptolemaeus, lit by the grazing light of sunrise. Photo by Jean Dragesco with a 14-inch Schmidt-Cassegrain, 400 ASA film, and a 2-second exposure at f/60.**

### Asteroids

1 Ceres (magnitude 8.8) lies in eastern Sagittarius as February begins, but moves eastward into adjoining Capricornus by the end of the month. Its positions:

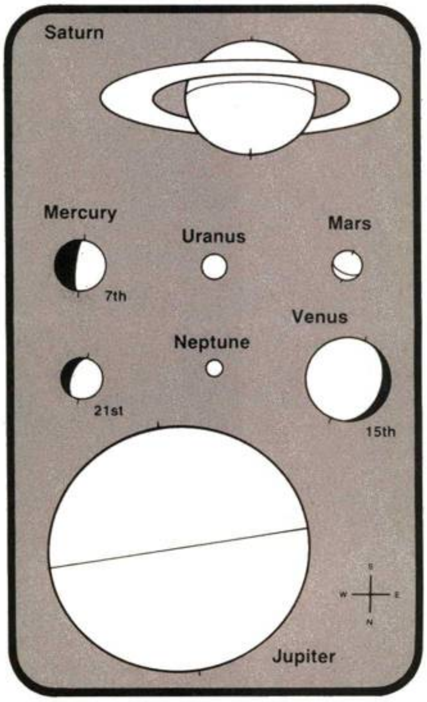
10th: 19h 50m 06s, −24° 39.8′
20th: 20h 06m 47s, −24° 13.5′

Ceres rises about 6:30 a.m. local time on the 15th.

2 Pallas (10.2) is moving toward the northeast in Ophiuchus. Its positions:

10th: 18h 17m 11s, +6° 05.6′
20th: 18h 19m 30s, +7° 08.6′

Pallas rises around 3:00 a.m. local time in mid-February.



3 Juno is in conjunction with the Sun on February 3. It will be out of sight until next month.

4 Vesta (8.3) lies near the joint borders of Aquarius, Cetus, and Pisces. Its positions:

10th: 23h 50m 51s, −6° 54.8′
20th: 00h 07m 27s, −5° 00.8′

Vesta sets about 8:00 p.m. local time on the 15th.

To facilitate plotting their positions on a star atlas, all asteroid coordinates are for the epoch 2000.0.

### Jupiter

Jupiter's family of moons encompasses some 16 individual bodies, but of these only four are easily visible from Earth. From the planet outward, they are Io, Europa, Ganymede, and Callisto. Sweeping around the planet in essentially co-planar orbits, Io circles once in 1d 18h 27m, Europa takes 3d 13h 13m, Ganymede 7d 3h 42m, and Callisto 16d 16h 32m. As they orbit Jupiter, they duck in and out of the planet's shadow and cross its disk.

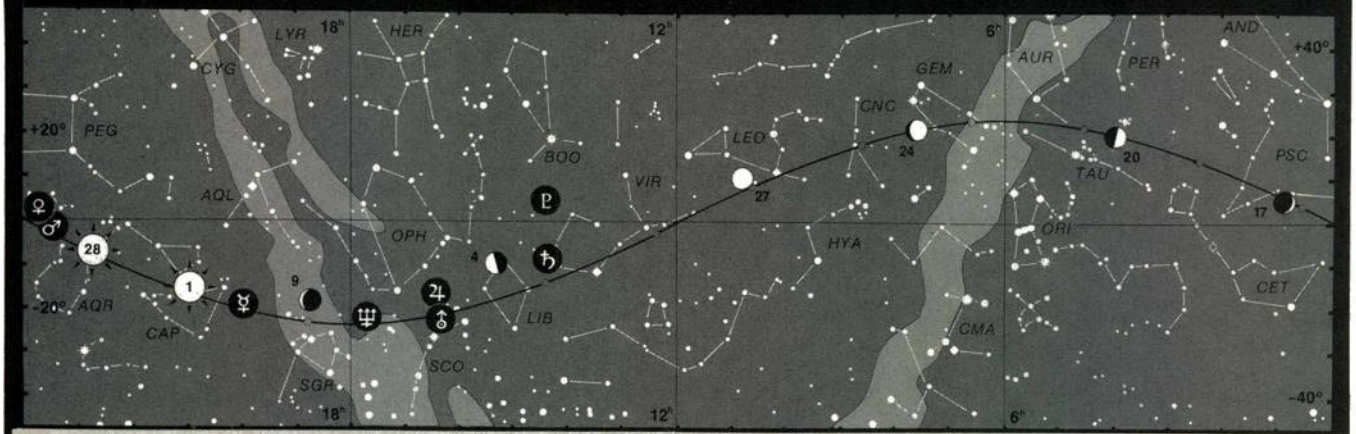
Io orbits so close to Jupiter that you'll only be able to see its disappearances into the planet's shadow — it reappears when it lies behind Jupiter from our point of view. You can see both the disappearance and the reappearance of Europa and Ganymede. Callisto orbits so far from Jupiter that it passes to the south of the cone of shadow behind Jupiter — the Sun is some 3° south of the jovian equator, whereas the moons orbit in the equatorial plane.

A great many events — transits, eclipses, occultations — occur each month among the jovian moons, but a few of the more outstanding are: On February 5 (9:21 UT), Io's shadow will start across the face of Jupiter, followed at 10:30 by the moon itself. At 10:57 the same day, Ganymede will disappear into the shadow of Jupiter, reappearing at 13:10. On the 11th, Europa will disappear into the shadow at 7:45 UT, will reappear at 10:07, be visible again for some 6 minutes, and then disappear behind Jupiter at 10:13. At 12:33, it will emerge from behind the planet.

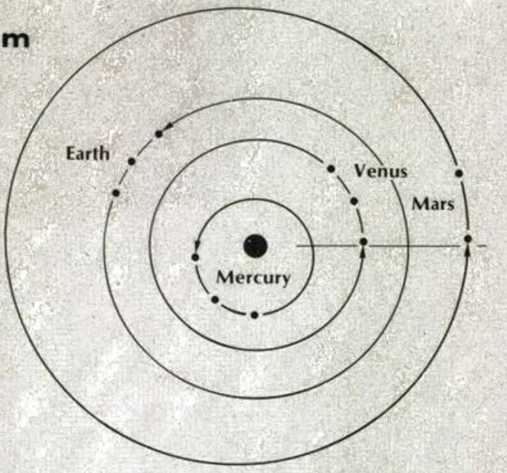
### Saturn

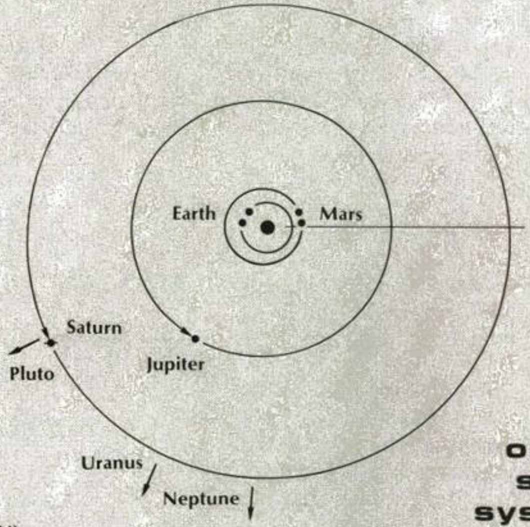
Because the Earth lies well away from the plane of the saturnian equator, we don't see with Saturn the eclipse and transit phenomena that the four bright moons of Jupiter display. At the start of February, the rings are tilted about 17° to

# planetary data february 1983


LYR
18h
HER
12h
6h
AND
+40°
CYG
GEM
AUR
PER
+20°
PEG
CNC
LEO
BOO
PSC
VIR
TAU
AQL
♀
♂
28
OPH
HYA
ORI
CET
1
4
9
-20°
AQR
☿
♆
♃
♅
♄
♇
LIB
CAP
CMA
SCO
SGR
18h
12h
6h
-40°
27
24
20
17

## inner solar system


Earth
Venus
Mars
Mercury


Earth
Mars
Saturn
Pluto
Jupiter
Uranus
Neptune

## outer solar system

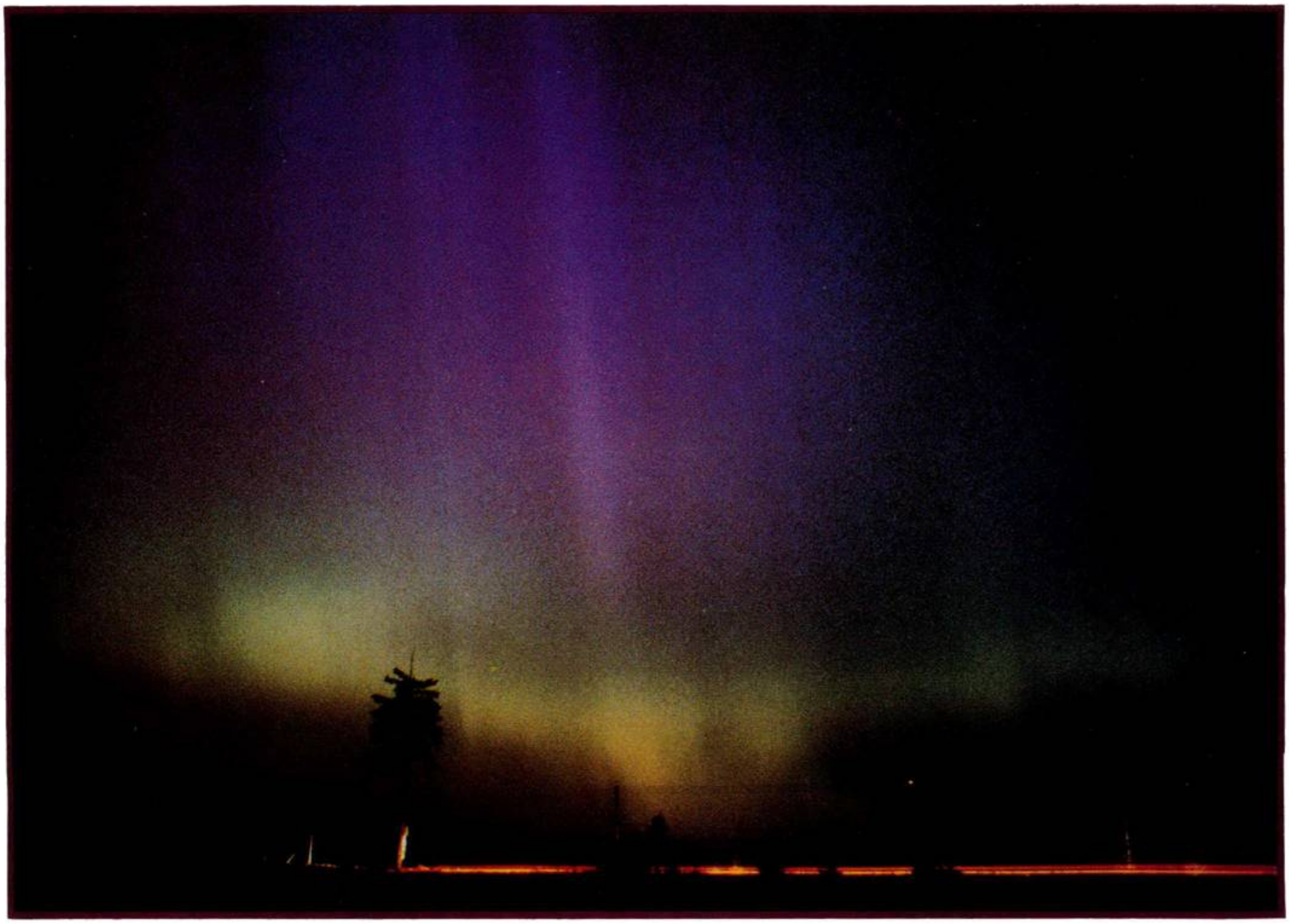
| | | Date | Mag. | Angular Size | % Illum. | Distance (AU) from: Earth | Sun | Longitude: Heliocentric | Ecliptic | R.A. (1983.2) | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sun** | | 1 | −26.8 | 32.5′ | — | 0.99 | — | — | 311°33.5′ | 20h 56.0m | −17°19.2′ |
| | | 15 | −26.8 | 32.4′ | — | 0.99 | — | — | 325°44.4′ | 21h 52.0m | −12°56.7′ |
| | | 28 | −26.8 | 32.3′ | — | 0.99 | — | — | 338°50.1′ | 22h 41.7m | −8°15.7′ |
| **Mercury** | ☿ | 1 | +0.4 | 7.8″ | 44% | 0.85 | 0.40 | 190°36.7′ | 287°21.5′ | 19h 15.4m | −20°16.1′ |
| | | 15 | +0.1 | 6.2″ | 71% | 1.08 | 0.46 | 235°03.0′ | 300°16.8′ | 20h 12.1m | −20°20.7′ |
| | | 28 | −0.1 | 5.4″ | 84% | 1.24 | 0.46 | 271°03.3′ | 318°17.2′ | 21h 26.8m | −16°55.3′ |
| **Venus** | ♀ | 10 | −3.3 | 11.1″ | 92% | 1.52 | 0.73 | 16°44.0′ | 343°34.3′ | 23h 03.3m | −7°34.9′ |
| | | 28 | −3.4 | 11.7″ | 89% | 1.44 | 0.72 | 45°30.5′ | 5°49.6′ | 0h 24.5m | +1°41.3′ |
| **Mars** | ♂ | 15 | +1.4 | 4.2″ | 98% | 2.22 | 1.40 | 10°35.2′ | 351°47.9′ | 23h 32.7m | −3°45.1′ |
| **Jupiter** | ♃ | 15 | −1.6 | 35.7″ | 99% | 5.51 | 5.38 | 238°06.5′ | 247°57.8′ | 16h 27.3m | −20°51.9′ |
| **Saturn** | ♄ | 15 | +0.7 | 17.8″ | 100% | 9.35 | 9.75 | 209°01.0′ | 213°58.4′ | 14h 12.2m | −10°34.0′ |
| **Uranus** | ♅ | 15 | +5.9 | 3.6″ | 100% | 19.13 | 18.93 | 245°51.8′ | 248°08.9′ | 16h 28.3m | −21°39.5′ |
| **Neptune** | ♆ | 15 | +7.8 | 2.4″ | 100% | 30.79 | 30.27 | 267°07.0′ | 268°08.1′ | 17h 54.3m | −22°12.9′ |
| **Pluto** | ♇ | 15 | +13.9 | 0.1″ | 100% | 29.47 | 29.90 | 207°42.3′ | 208°54.3′ | 14h 13.8m | +4°52.9′ |

## moon data

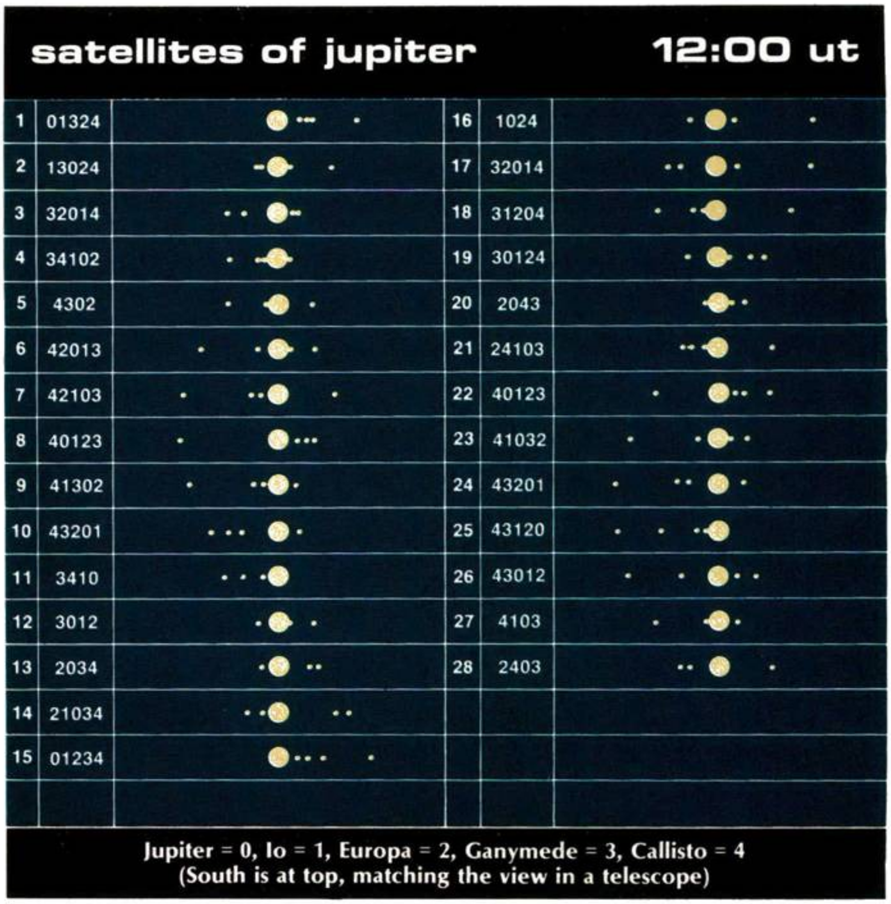
| | |
|---|---|
| Last Quarter ......... | February 4 at 19:17 |
| New Moon .......... | February 13 at 00:32 |
| First Quarter ......... | February 20 at 17.32 |
| Full Moon .......... | February 27 at 8:58 |
| Last Quarter .......... | March 4 at 13:16 |
| New Moon ........... | March 14 at 17:43 |
| Apogee: February 10 at 8h ... | 406,264 km |
| Perigee: February 25 at 22h ... | 360,200 km |

## universal time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times in The Backyard Astronomer are UT unless otherwise noted. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska and Hawaii, 10. For example, if an event is to happen at 03:00 hours UT on February 2, then EST for the event is 10 p.m., February 1. Likewise, 03:00 UT on March 5 becomes, in PST, 7 p.m., March 4.



**Jerry Cotey caught this colorful aurora on August 6, 1982 near Sheldon, Washington. He photographed it by placing his camera (loaded with 400 ASA film) on a tripod, aiming it upward, setting the focus of his 28mm lens to infinity, opening the aperture all the way, and exposing for 15 seconds.**



## satellites of jupiter 12:00 ut

| | | | |
|---|---|---|---|
| 1 | 01324 | 16 | 1024 |
| 2 | 13024 | 17 | 32014 |
| 3 | 32014 | 18 | 31204 |
| 4 | 34102 | 19 | 30124 |
| 5 | 4302 | 20 | 2043 |
| 6 | 42013 | 21 | 24103 |
| 7 | 42103 | 22 | 40123 |
| 8 | 40123 | 23 | 41032 |
| 9 | 41302 | 24 | 43201 |
| 10 | 43201 | 25 | 43120 |
| 11 | 3410 | 26 | 43012 |
| 12 | 3012 | 27 | 4103 |
| 13 | 2034 | 28 | 2403 |
| 14 | 21034 | | |
| 15 | 01234 | | |

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)

our line of sight. Over the next few months, they will gradually close up again, reaching the minimum for the year (14.6°) in late June. By year's end, however, they will have opened up again to a little more than 20°.

It's interesting to observe the rings; the outermost you can see in a small telescope is the A ring. It is separated from the next ring inward — the broad B ring — by a 3500 km-wide dark gap called the Cassini division. Inside the B ring is a thin, dim ring called the C, or "crepe," ring. Your best chance of seeing the C ring is to look where it crosses the disk of Saturn, making a dusky streak. Anyone with a large telescope should try to see the A ring's Encke division, a narrow (270 km) dark gap near the outer edge of the A ring — but to spot it, you'll need superb seeing.

### Uranus

During February, Uranus will lie about 30′ of arc south and 3 minutes of R.A. west of the 4.6 magnitude star Omega (ω) Ophiuchi. This region lies a few degrees north of Antares, the brightest star in Scorpius. Uranus will have a 5.9 magnitude disk, 3.6" of arc across.

### Neptune

The easiest way to spot Neptune during most of this year will be to use the bright Trifid Nebula (M-20) as a guide. During February, the planet will lie about a degree north and 8 minutes (on the 1st) to 6 minutes (on the 28th) west of the nebula. Neptune's disk, 2.4" of arc across, will shine at 7.8 magnitude.

## close-up on canis major

One of the brightest of all constellations, **Canis Major** is a popular telescopic hunting ground for deep-sky observers who brave the winter cold. The Great Dog sits at Orion's feet, displaying a variety of celestial objects such as open clusters, double and variable stars, odd gaseous nebulae, a planetary nebula, and even some faint galaxies that shine through the Milky Way's obscuring gas and dust.

Probably the most popular deep-sky target in the region is **M-41**, a bright open cluster composed of 100 suns ranging in luminosity from magnitude 7 to 13. M-41 lies about 4° south of Sirius, and is a fine sight in binoculars. In 4¼-inch to 8-inch telescopes at low powers, its total magnitude of 5.0 and diameter of 32′ combine to make it a dazzling sight. The group is about 2,350 light-years distant, giving it a true diameter of about 20 light-years. M-41 is a fairly loose cluster, so you'll want to stay with low powers when you observe it.

Two other bright open clusters in the region are **NGC-2360** and **NGC-2362**. NGC-2360 spans 10′ and contains 50 stars that shine between magnitudes 9 and 12. It isn't as striking as M-41, but is a nice sight in scopes of medium to large aperture. NGC-2362 is much brighter, since it contains the 4th magnitude star Tau (τ) Canis Majoris and a smattering of magnitude 8 to 13 stars. The diameter of the group is only 6′, so it appears "rich" in comparison to M-41. This is a great high-power object: after you've found it, crank up the magnification on your scope to about 25x per inch of aperture, and you should get a pleasing view. Interestingly, τ CMa seems to be an actual member of the group, lying at a distance of about 4,600 light-years. If this is true, the star is one of the most luminous known. Placed at the same distance from us as Sirius, it would shine at magnitude -9.6 — as bright as the First Quarter Moon.

Several faint galaxies are strewn around the region, including **NGC-2207**, a spiral shining at magnitude 12.3. This galaxy measures only 2.5′ x 1.5′ and at its magnitude is a challenging object for backyard telescopes, but a 12-inch or 16-inch scope under dark skies should

Orion, the Hyades, and the Pleaides were setting over the rim of Tajo Canyon, Baja California, when Jerry Schad took the photo that nets him this month's "Best Astro-Photo" award. An 11-day-old Moon lit the rocks as he exposed 400 ASA film for 25 seconds at f/2; his lens had a 35mm focal length.

**Despite being 11th magnitude, NGC-404 is an easy galaxy to find since it lies only 6.4' of arc to the northwest (lower left in photo) of the 2nd magnitude star Beta Andromedae. Jack Newton photographed it with his 16-inch Newtonian using an 18-minute exposure on 400 ASA film in a cold camera.**

show it pretty well. The same is true of barred spirals **NGC-2217** and **NGC-2223**, both of which glow at magnitude 12.5 and measure slightly larger than NGC-2207. These galaxies are suitable for large backyard scopes, and can be conveniently found on a detailed atlas such as Tirion's *Sky Atlas 2000.0*. If these spirals were located farther away from the plane of the Milky Way, they would be brighter and more impressive objects.

**NGC-2327** and **NGC-2359** are two unusual gaseous nebulae. NGC-2327 occupies an area of 20′ and shines by reflecting starlight from a 10th magnitude double star. It is a difficult object to observe, but can be glimpsed with a 16-inch or 20-inch telescope. NGC-2359 is an emission nebula, shining by fluorescence, and is brighter than NGC-2327. Visible in a 6-inch telescope, it surrounds a small group of stars. The brightest parts of each of these nebulae probably shine at around 12th or 13th magnitude.

Another nebulosity in the constellation is **IC-2165**, a tiny planetary nebula surrounding a very faint star. You'll need a 10-inch or 12-inch telescope to observe this little ball of gas, which radiates at magnitude 12.5. Since the nebula measures only 8′ across, medium to high powers are essential in identifying it as a nebula rather than a faint star.

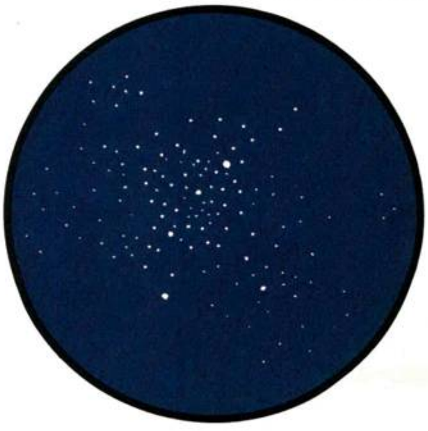
Several interesting stars lie within Canis Major. One captivating star is **W Canis Majoris**, a reddish irregular variable that pulsates from 7th to 8th magnitude. Because it varies over a small magnitude range at no predictable period, you'll have to be careful when you estimate its brightness. Compare it with nearby stars of similar, known brightness. Since reddish stars affect your ability to estimate magnitudes when you stare at them, don't stare at W for long periods of time — glance at it quickly. **R Canis Majoris** is another nice variable within the constellation; it is an eclipsing binary, varying from magnitude 5.9 to 6.6 over a period of 1.1 days.

A large number of double stars resides in this part of the sky, among which is **Nu$^1$ ($\nu^1$) Canis Majoris**. This pair is composed of magnitude 6.5 and 8.0 stars, separated by 17.5′. Thus it can easily be split at medium powers, and its colors of rust and pale violet make an attractive sight. Another fine double star is **h3945**, a pair from the John Herschel catalog. The two components shine at magnitudes 5.0 and 7.0, are separated by 26.6′ and are colored gold and blue — so it looks like a miniature Albireo. To observe each of these pairs, use about 12x to 15x per inch of aperture on dark nights. You'll be rewarded with some fine views, and maybe you won't miss Albireo so much until it appears again.

**Sirius** ($\alpha$ Canis Majoris) is the brightest star in the sky, shining at magnitude -1.5. It is a remarkable star: only 8.7 light-years away, it glows with the luminosity of 23 Suns, measures almost twice the solar diameter, and contains more than twice the Sun's mass. It is also an extremely difficult double star. At magnitude 8.0, its companion — Sirius B — is the brightest known white dwarf star. The two stars are separated by 9″, but the extreme difference in brightness makes the two difficult to separate. It is possible to observe Sirius B in a 6-inch reflector, but such a sighting is extremely rare. Trying to see it in a 12-inch telescope is more reasonable, although certainly not easy. Go after it on a very steady night, placing an occulting bar — a thick wire or something similar — over the bright image of Sirius in your eyepiece. If you think you see the companion, rotate the eyepiece to see if it stays in the same place and isn't a reflection. If it remains steady, you may well have found Sirius B.

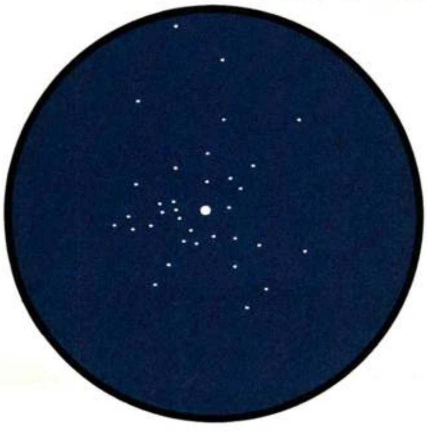
Canis Major offers a great variety of celestial objects for you to observe with your telescope. If you get out and look, you can see deep-sky objects that are largely typical of the winter stretch of the Milky Way: bright open clusters, a strange planetary nebula, big loops of emission and reflection nebulosity, colorful double and variable stars, and even a few faint galaxies. *This selection is a big incentive* for you to lug your scope out into the cold, plop in an eyepiece, and enjoy the universe.

**M-41** **8-inch reflector at 50x**



Sketch by David J. Eicher

**NGC-2362** **8-inch reflector at 70x**

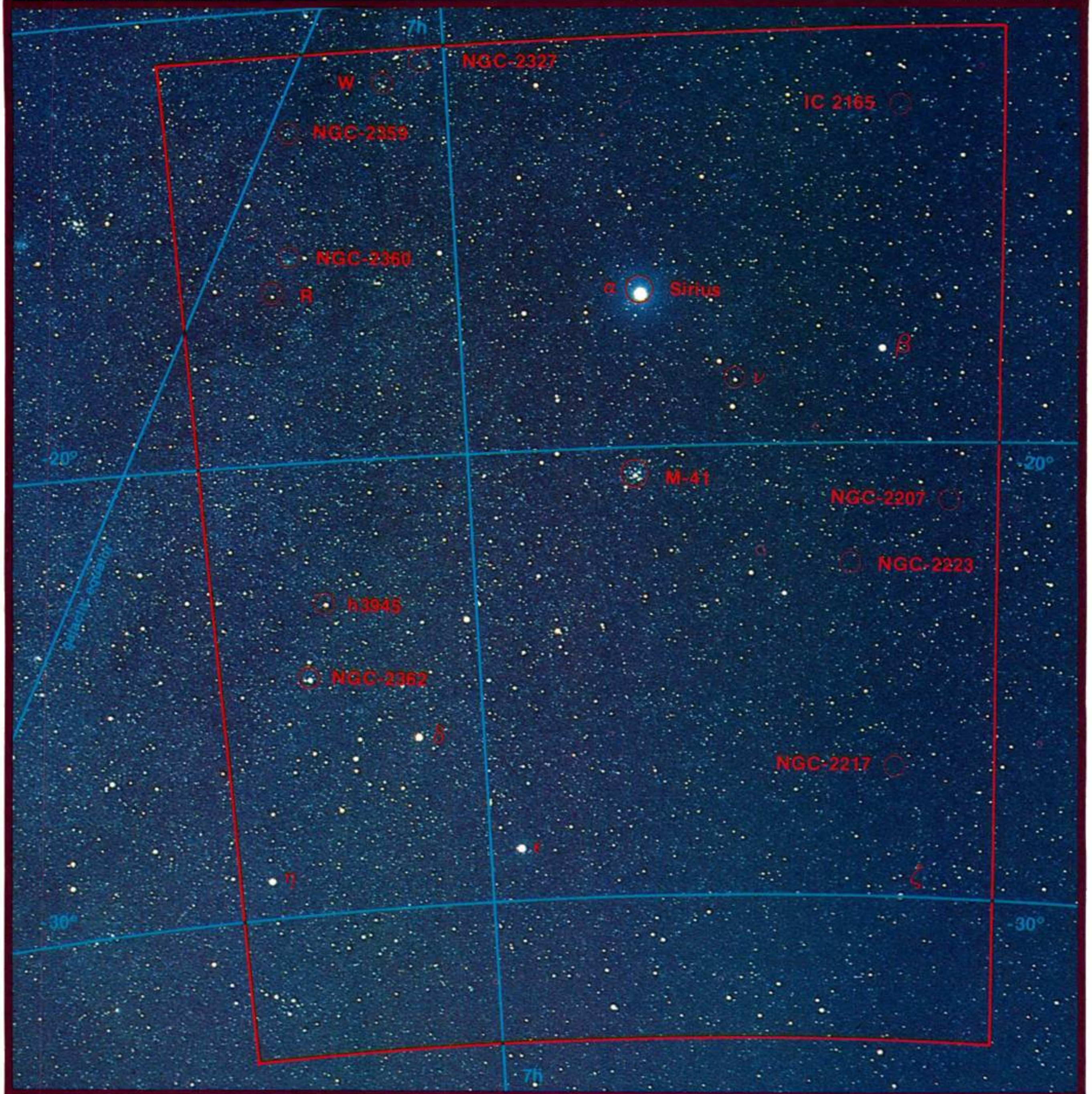


Sketch by David J. Eicher

# canis major

photo by Brad Wallis & Robert Provin

map by Robert Burnham


7h
NGC-2327
W
IC 2165
NGC-2359
NGC-2360
R
α
Sirius
β
ν
-20°
M-41
-20°
NGC-2207
NGC-2223
galactic equator
h3945
NGC-2362
δ
NGC-2217
ε
η
ζ
-30°
-30°
7h

| Object | Type | Mag. | Size/Sep. Per. | R.A. (1950) Dec. | | R.A. (2000) Dec. | |
|---|---|---|---|---|---|---|---|
| NGC-2207 | §S | 12.3 | 2.5′x1.5′ | 6h14m | -21°21′ | 6h16m | -21°22′ |
| NGC-2217 | §S | 12.0 | 4.0′x3.0′ | 6h19m | -27°14′ | 6h21m | -27°15′ |
| IC 2165 | ■ | 12.5 | 8″ | 6h20m | -12°57′ | 6h22m | -12°59′ |
| NGC-2223 | §S | 12.7 | 3.5′x2.5′ | 6h23m | -22°49′ | 6h25m | -22°51′ |
| Nu$^1$ ($\nu^1$) | ★$^2$ | 6.5+8.0 | 17.5″ | 6h34m | -18°37′ | 6h36m | -18°40′ |
| Sirius ($\alpha$) | ★$^2$ | -1.5+8.0 | 10.8″ | 6h43m | -16°39′ | 6h45m | -16°42′ |
| M-41 | ○ | 5.0 | 32′ | 6h45m | -20°42′ | 6h47m | -20°45′ |
| NGC-2327 | □ | 13? | 20′ | 7h02m | -11°14′ | 7h04m | -11°19′ |
| W | ∩★ | 7.03→18.0 | Irr | 7h06m | -11°51′ | 7h08m | -11°56′ |
| h3945 | ★$^2$ | 5.0+7.0 | 26.6″ | 7h15m | -23°13′ | 7h17m | -23°17′ |
| NGC-2359 | □ | 12? | 6′x8′ | 7h15m | -13°07′ | 7h18m | -13°12′ |
| NGC-2360 | ○ | 9.0 | 10′ | 7h15m | -15°33′ | 7h18m | -15°38′ |
| NGC-2362 | ○ | 4.0 | 6′ | 7h17m | -24°52′ | 7h19m | -24°58′ |
| R | ꓤ★ | 5.9→6.6 | 1.1d | 7h17m | -16°18′ | 7h19m | -16°24′ |

| | |
|---|---|
| ★ | *Star* |
| ★$^2$ | *Double Star* |
| ★$^3$ | *Triple Star* |
| m★ | *Regular Variable* |
| ∩★ | *Irregular Variable* |
| ꓤ★ | *Eclipsing Variable* |
| ○ | *Open Cluster* |
| ● | *Globular Cluster* |
| ■ | *Planetary Nebula* |
| □ | *Bright Diffuse Nebula* |
| §0 | *Elliptical Galaxy* |
| §S | *Spiral Galaxy* |
| §ʃ | *Barred Spiral Galaxy* |
| §# | *Peculiar/Irregular Galaxy* |

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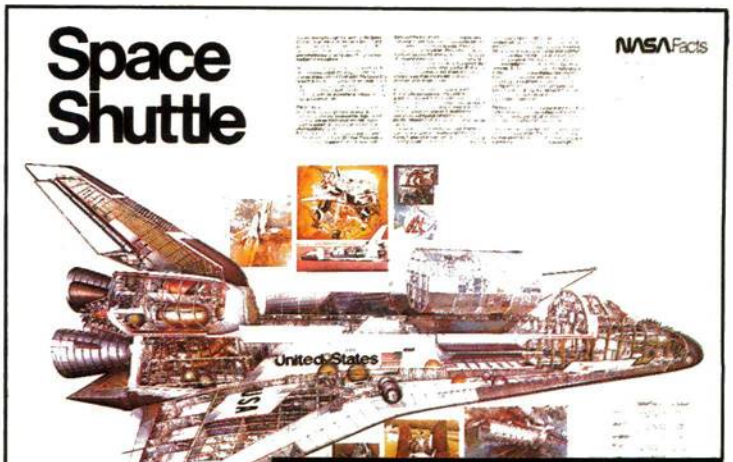

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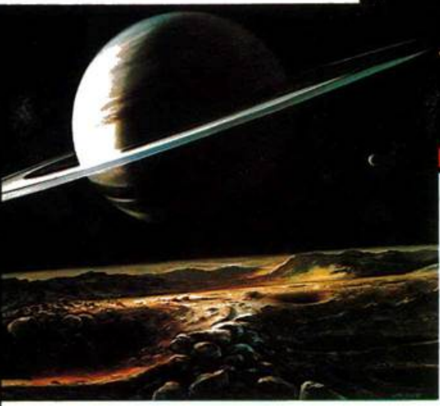

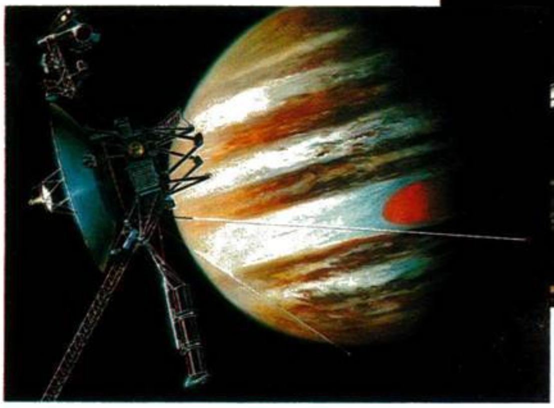

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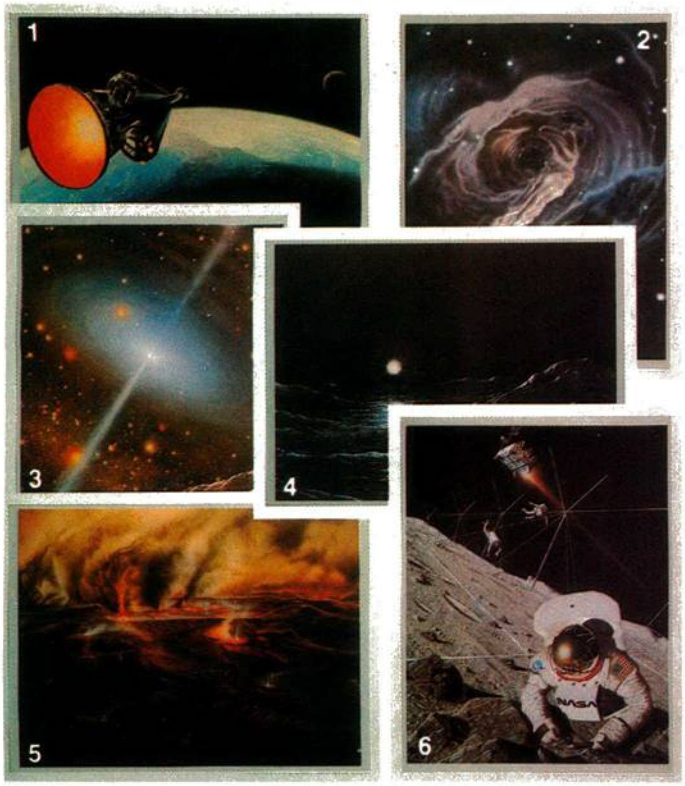

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